concawe

report no. 8/05

the impact of reducing sulphur to 10 ppm max in european automotive fuels

an update

Prepared by the CONCAWE Refinery Technology Support Group (RTSG)

M. Dastillung (Chairman)

S. Bottino
A. Courbes
J. Garcia Ocana
N. Gudde
C. Lyde
A. Mackenzie
P. Nunez
H-D. Sinnen
R. Sinnen

J-F. Larivé (Technical Coordinator)

M. Fredriksson (Consultant)

Brussels
August 2005

ABSTRACT

The cost and CO_2 emissions associated with the reduction of sulphur in EU road fuels have been evaluated using the CONCAWE EU refining model. The results are compared to those of a similar study carried out in 2000.

In order to reduce sulphur in road fuels to less than 10 ppm, the EU refining industry is set to invest some 7 G€ while increasing its CO_2 emissions by 7.3 to 9.2 Mt/a. This is in addition to about the same investment and a CO_2 emissions increase of 13Mt/a to meet demand evolution.

KEYWORDS

Gasoline, diesel fuel, sulphur, refinery investment, CO_2 emissions.

INTERNET

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

CONTENTS

SUMMARY

The cost and CO_2 emissions associated with the reduction of sulphur in EU road fuels have been evaluated using the CONCAWE EU refining model. The results are compared to those of a similar study carried out in 2000.

The main estimates were produced on the basis of a relatively favourable core scenario. Sensitivities were carried out to show the potential additional effects of heavier crude slate, higher energy usage and the imposition of road diesel quality to all EU non-road diesel.

The following table summarises the results in terms of incremental annualised cost and CO_2 emissions from the refining sites.

	2000	2010							
	Base	Reference	Alternatives						
Refinery production (Mt/a)									
Gasoline	*136*	*136*							
Diesel fuel	*140*	*195*							
Study Case	Gasoline 150 ppm diesel 350 ppm	Gasoline 150 ppm diesel 350 ppm	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Nominal sulphur specification (ppm max)									
Gasoline	*150*	*150*	*50*	*10*	*10*	*50*	*10*	*10*	*50*
Diesel fuel	*350*	*350*	*50*	*10*	*50*	*10*	*10*	*50*	*10*
Other key specifications									
Gasoline aromatics (% v/v max)	*42.0*	*35.0*							
IGO sulphur (% m/m max)	*0.2*	*0.1*							
Capital investment (G€)		Additional to base	Additional to reference				Additional to 50ppm for both fuels		
Core scenario		**7.3**	**2.9**	**6.7**	**4.8**	**4.8**	**3.8**	**1.9**	**1.9**
Sensitivity 1(*)		8.8	3.1	6.9	5.1	5.0	3.9	2.1	1.9
Sensitivity 2		7.4	3.0	6.8	4.9	4.8	3.8	1.9	1.8
Sensitivity 3		7.4	2.8	6.6	4.7	4.6	3.8	1.9	1.8
Sensitivity 4		7.6	3.1	7.3	5.1	5.3	4.2	2.0	2.3
Sensitivity 5		8.8	3.5	7.5	5.6	5.8	4.0	2.0	2.2
Overall annualised cost (G€/a)			Additional to reference				Additional to 50ppm for both fuels		
Core scenario			**0.84**	**1.89**	**1.38**	**1.34**	**1.05**	**0.54**	**0.50**
Sensitivity 1			0.78	1.82	1.37	1.25	1.05	0.59	0.47
Sensitivity 2			0.78	1.85	1.37	1.25	1.07	0.59	0.47
Sensitivity 3			0.76	1.82	1.35	1.24	1.05	0.58	0.47
Sensitivity 4			0.83	1.97	1.41	1.38	1.14	0.58	0.55
Sensitivity 5			0.89	2.05	1.50	1.44	1.16	0.61	0.55
Site CO2 emissions (Mt/a)	Additional to ref	Total	Additional to reference				Additional to 50ppm for both fuels		
Core scenario	**-13.3**	**154.5 (*)**	**3.5**	**7.3**	**5.9**	**4.6**	**3.8**	**2.5**	**1.1**
Sensitivity 1	-19.1	160.3	3.6	7.6	6.4	5.0	4.1	2.9	1.4
Sensitivity 2	-13.3	154.5	3.5	7.9	6.5	4.7	4.4	3.0	1.3
Sensitivity 3	-20.5	161.7	3.5	7.7	6.2	4.9	4.2	2.7	1.4
Sensitivity 4	-13.4	154.6	3.8	8.2	6.5	5.3	4.3	2.7	1.5
Sensitivity 5	-26.8	168.0	4.3	9.2	7.4	5.7	5.0	3.2	1.4

(*)Sensitivities
1: Heavier crude slate (5% shift towarsd heavy crude)
2: 50% higher energy consumption for FCC gasoline desulphurisation
3: Energy efficiency unchanged from 2000
4: Non-road diesel at AGO spec
5: Combined changes
(*)138 when excluding petrochemicals

Sulphur reduction of road fuels beyond the 2000 specifications will require an estimated refinery capex of 2.9 to 3.5 G€ to 50 ppm sulphur and 6.7 to 7.5 G€ to 10 ppm. Gasoline and diesel equally share the difference of 4 G€ between the two target limits.

These investment figures are in addition to another 7.3 G€ required to meet the evolution of demand and the changes to other specifications between 2000 and 2010. This figure would rise to nearly 8.8 G€ with a heavier crude slate.

The EU refineries will emit an estimated additional amount of CO_2 of 3.5 to 4.3 Mt/a to 50 ppm sulphur and 7.3 to 9.2 Mt/a to 10 ppm. Gasoline is responsible for 65% and diesel fuel for 35% of the difference of 4 to 5 Mt/a between the two target limits.

In order to cope with demand evolution and with the changes in other specifications between 2000 and 2010, EU refineries will further increase their CO_2 emissions by 13.3 Mt/a, increasing to 26.8 Mt/a in the worst scenario considered.

The annualised costs to EU refineries will increase by 0.8 to 0.9 G€/a to 50 ppm sulphur and 1.8 to over 2 G€/a to 10 ppm. Gasoline is responsible for just over half of the difference of 1.1 G€/a between the two target limits, the balance being attributable to diesel.

This is equivalent to around 2.8 € per tonne of low sulphur fuel produced to 50 ppm and 6.2 €/t to 10 ppm.

When considering the change from 50 to 10 ppm sulphur for both gasoline and diesel, the new estimates represent about 2/3 of the overall costs and of the additional CO_2 emissions estimated in the 2000 CONCAWE study. These changes are the result of the very significant technology developments that have taken place in the intervening period, as well as changes in predicted 2010 demands and crude slate.

It must be kept in mind that the model estimates the overall effect of a change on the industry. In practise each refinery will seek the most cost-effective route to address its own specific set of technical, financial and other constraints. When expressed as a percentage of the total, the increased CO_2 emissions estimated by the model should therefore only be regarded as an average of a wide range of values. Individual circumstances (crude intake, refinery technology, product mix) will dictate the scale of the actual increase for any given refinery.

1. INTRODUCTION

In May 2000 the EU Commission issued a “call for evidence” to evaluate the potential benefits and drawbacks of reducing the sulphur specification of European road fuels beyond the 50 ppm limit foreseen by the 1998 Fuels Directive and due to take effect in 2005. On this occasion CONCAWE undertook a study to evaluate the additional costs that the EU refining industry would incur and the extra CO_2 that refineries would emit, should sulphur be reduced to less than 30 or 10 ppm. This work was reported in CONCAWE report 00/54 [1].

For the 2000 study the CONCAWE model was adapted to represent the technologies available for deep sulphur reduction of gasolines and diesel fuels. At the time, many of these technologies were still under development and some of the technical data was of a preliminary nature. In the past 4 years, technology development in this field has advanced at a tremendous rate. New and improved catalysts have been put on the market, existing processes have been improved, entirely new processes have been developed and a number of refiners have started to produce these sulphur-free fuels.

The 2000 study was based on EU-15. This report evaluates the impact for the whole of Europe including EU-25, Norway and Switzerland and the future accession States.

In view of such major evolutions, it was justified to revisit the issue and make a completely new evaluation of the cost and CO_2 effects of sulphur reduction in automotive fuels.

This report details the premises and the results of this new study undertaken by CONCAWE’s Refinery Technology Support Group.

2. MODELLING TOOL AND METHODOLOGY

2.1. THE CONCAWE MODEL

This study was conducted using the CONCAWE EU refining model. This model uses the linear programming technique to simulate the European refining system. As such the model proposes an “optimised” feasible solution to a particular set of premises and constraints, on the basis of an economic objective function.

In the CONCAWE studies, the main objective is to evaluate the extra costs, energy and CO_2 emissions that would result from certain regulatory measures. Such changes would, in real life, probably have an impact on e.g. feeds and product prices, but there is no objective way to forecast this. Instead the model is forced to find a solution by using the single mechanism of additional plant capacities while feed and product prices are kept constant. The LP technique is therefore mainly used here to find a feasible solution to a complex problem. The costs to the industry accrue from the capital required to build new plants and the extra cost incurred to run them, including the cost of extra energy. The extra CO_2 emissions result from the energy usage.

The modelling work starts from a “current” **base case** for which the model can be calibrated with real data. For this study the base case is the year 2000. The plant capacities required to meet the base case demand and qualities (which should of course be close to the actual ones) are then frozen.

A future year is then selected for which crude supply, product demand and quality forecasts must be available (2010 for this study). Next a future year **reference case** is established, usually the “business-as-usual” case in which only already agreed and/or legislated changes are included. From this point all future demands as well as the crude diet are fixed. Only one crude (Heavy Middle East) is allowed to vary to balance the requirements (e.g. for energy).The model is allowed, at a cost, to increase the capacity of existing units as well as use new units and must use this mechanism for meeting the constraints.

Alternative cases are run from the base case, with the same basic crude supply and product demand figures and with specific additional constraints, thereby providing alternative paths to the future compared to the reference case. This approach assumes that all alternatives would be developed within the same timeframe. If this is not the case, there can be “regret” investment in the reference case. Note that this would only affect cost and not energy and CO_2 emissions as, in some alternative case, the model would simply not use some of the capacity “installed” in the reference case. Usually separate runs of the model are not required for this analysis as the extra costs to be considered will be apparent from the concurrent runs.

A reference case and its alternatives share a common set of underlying assumptions and differ only according to changes in the specific parameter(s) under study (in the present case the sulphur content of road fuels). In some cases sensitivity scenarios may be run, comprising of a different reference case and alternatives with a different set of assumptions. This study includes such sensitivity scenarios described in **Section 3.3**.

The CONCAWE model splits Europe into 9 regions, each of which is represented by a composite refinery having, for each process unit, the combined capacity of all refineries in the region (**Table 1**).

Table 1 The 9-regions of the CONCAWE EU refining model

Region	Code	Countries	Total crude distillation capacity Mt/a
Scandinavia	SCA	Denmark, Finland, Norway, Sweden	54
UK & Ireland	UKI	Great Britain, Ireland	91
Benelux	BEN	Belgium, Luxembourg, Netherlands	97
Mid-Europe	MEU	Austria, Germany, Switzerland	131
France	FRA	France	95
Iberia	IBE	Portugal, Spain	79
Italy & Greece	ITG	Cyprus, Greece, Italy, Malta	138
Eastern Europe	EEU	Baltic States, Czechia, Hungary, Poland, Slovakia, Slovenia	59
South Eastern Europe	SEU	Albania, Bosnia, Bulgaria, Croatia, Macedonia, Romania	55

The first 8 regions represent EU-25+2 (Norway and Switzerland). The last region includes countries not yet integrated into the EU but with which the EU already has product exchanges. For this reason they have been included into the model although their impact is small.

In previous CONCAWE studies each region was further divided into four refineries with different configurations. As product specifications tighten, refineries increasingly have to rely on component exchanges to optimise blends and meet quality constraints. As a result very few refineries operate in complete isolation and we consider that the degree of “over-optimisation” brought about by the single refinery aggregation is sufficiently limited to not significantly distort the results.

Another significant change has been the inclusion of a simple representation of the petrochemical industry in terms of olefins and BTX production. This allows the model to take full account of the synergies and constraints that are brought about by this important interface.

Exchanges of key components and finished products between regions are allowed at a cost.

2.2. PRODUCT SPECIFICATIONS VERSUS PRODUCTION LEVELS

When a product specification is constraining refinery operations, “giving-away” quality, i.e. producing a better quality than allowed by the specification, costs money. Refiners therefore endeavour to produce as close to the specification as possible. There are many reasons why there always remains a gap between specification and actual production often referred to as the production margin. A mathematical model will of course always converge towards the actual specified figure so that the margin has to be reflected in the model by specifying a lower (or higher) figure than the actual specification.

This is particularly relevant for very low levels of sulphur. In addition to the normal operating margin, it is considered that refiners will have to apply an extra margin to accommodate accidental contamination in the storage and distribution system. Accordingly we have run the model to a target of 7 ppm to represent the 10 ppm specification.

We have also considered that, at this level of sulphur, blending would not be an option and therefore that all components must individually meet the 7 ppm target. In the same way we have allocated the same 7 ppm level of sulphur to all blending components (e.g. MTBE) so that the model would not be able to use them as “sulphur diluent”.

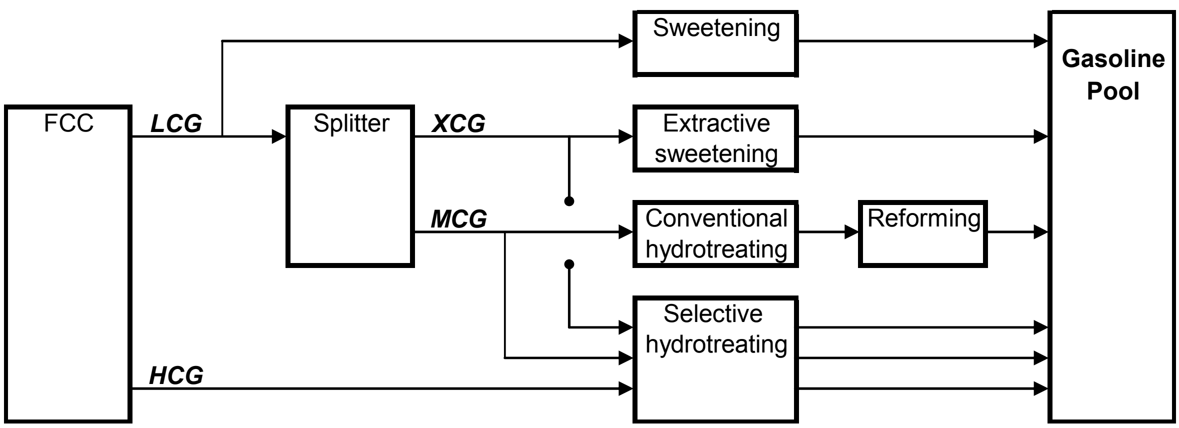
Similarly the 50 ppm specification has been modelled as 40 ppm.

2.3. MODELLING OF GASOLINE DESULPHURISATION

The vast majority of the sulphur in gasoline comes from FCC components. The technologies available to refineries to treat these streams have greatly improved since the previous CONCAWE reports in 1999 & 2000 were published [1,2]. At the time, selective hydrotreatment technologies were in development and were still resulting in significant saturation of olefins with associated octane loss. A favoured route was deep desulphurisation of heart-cut cracked gasoline followed by reforming. This route is energy-intensive and results in an increase in aromatics in the pool which has to be compensated with other components. Several processes are now commercially available to directly reduce sulphur in cracked gasoline to very low levels with very limited loss of octane.

The CONCAWE model construction has been modified to include a representation of such processes as illustrated in **Figure 1**. The full range cracked gasoline can be split into either 2 or 3 streams (Heavy HCG, Light LCG itself split into Medium MCG and Extra light XCG). HCG can be selectively hydrotreated to reduce sulphur. Alternatively it can be used in the gasoil pool. LCG and XCG can be sweetened or selectively hydrotreated while MCG can either follow the reforming route mentioned above or be selectively desulphurised. Note that selective desulphurisation can also be applied to other olefinic streams e.g. from steam crackers (not shown in the figure).

Figure 1 Cracked gasoline desulphurisation options



2.4. MODELLING OF DIESEL DESULPHURISATION

At the time of previous CONCAWE work, reducing sulphur in diesel fuel to less than 10 ppm was considered as a major challenge. It was generally believed that reaching 10 ppm in a single processing step would be achievable only with the lightest and least sulphurous feeds. For cracked streams some de-aromatisation was thought to be inevitable in order to reach such low levels. The options considered therefore included double processing and use of noble metal catalysts to remove the most refractory sulphur compounds, thereby also achieving significant levels of de-aromatisation.

Desulphurisation technology and more particularly catalyst technology have made great strides over the last 5 years and it is today possible to go under the 10 ppm level with traditional hydrodesulphurisation units (HDS) and at relatively modest pressure levels. This can be achieved even with a proportion of cracked material in the feed although higher pressure levels tend to be required for such mixtures. This has resulted in some reduction of energy usage and hydrogen consumption.

The CONCAWE model recognises that this opens the opportunity to refurbish older HDS units as long as their operating pressure is sufficient for the new catalysts thus saving on the investment required in new hardware (but not on hydrogen or process energy).

De-aromatisation is also available to the model but should not be required for reduction of sulphur to less than 10 ppm.

The model provides for straight-run kerosene desulphurisation to either jet fuel quality or sulphur-free diesel quality. Straight-run and cracked gasoils can be desulphurised to three levels depending on the requirement of the diesel and gasoil grades. The model recognises three types of HDS units according to the range of operating pressure (low, medium and high pressure for <30, 30-50, >50 bar of hydrogen partial pressure). Only the medium and high pressure units are deemed to be suitable for production of less than 10 ppm streams, although the medium pressure units lose capacity when operated at the higher severity. Desulphurised gasoil and kerosene to less than 50 ppm can be further de-aromatised.

Notes:

Novel desulphurisation processes

The desulphurisation schemes represented in the model correspond to what can be considered as commercially proven today. There are, however, other processes in various stages of development that utilise radically different technologies to remove sulphur resulting in virtually no hydrogen consumption and, for gasoline, lower octane losses. BP's OATS® and ConocoPhillips's S-Zorb® are examples of such processes. How successful these new developments will be remains to be seen but their widespread use would in all probability further reduce the hydrogen and energy consumption and therefore CO_2 emissions attached to desulphurisation.

Hydrogen production and consumption

The hydrogen consumption of hydrotreating units is calculated on a stoichiometric basis from assumed level of sulphur removal, aromatics and olefins conversion. In practice a surplus of hydrogen is needed to operate these plants, which eventually finds its way into fuel gas. In order to represent this, the hydrogen production units[1]

[1] Beside the catalytic reformer, hydrogen can be produced by steam reforming of natural gas and residue gasification followed by carbon monoxide conversion (CO-shift)

are required to produce 15% more hydrogen than the demand. The extra hydrogen is routed directly to fuel gas. Similarly a portion of the hydrogen produced in the catalytic reformers cannot be used for hydrotreating purposes.

2.5. COST ESTIMATION

The CONCAWE model uses the LP technique and is therefore driven by an economic function. The cost of new plants is represented in the model by an extra variable cost per tonne of feed. Whereas this is adequate to drive the model and obtain a feasible solution, this single capacity cost figure is too simplistic. The cost of investments is therefore recalculated “off-line” on the basis of the new capacity required, the capacity already installed, the number of refineries in the regions and whether the type of unit would typically have to be installed in every refinery or could conceivably be “shared” between refineries (e.g. the requirement for say sweetening capacity would be reflected in every refinery whereas the need for residue desulphurisation could be met by one or a small number of “shared” plants). The details of the logic used are described in **Appendix 1** together with the capital cost of the most relevant process units.

2.6. ESTIMATION OF CO_2 EMISSIONS

The direct CO_2 emissions of a refinery stem from the fuel(s) that is burned on site as well as the “chemical” CO_2 rejected as part of hydrogen production by methane steam reforming or possibly residue gasification and syngas conversion. The former represents by far the largest portion, the latter only becoming significant in refineries with large hydrocracking or residue hydroconversion facilities.

From a global point of view CO_2 emissions will also occur when refinery fuel products are actually burned.

CO_2 emissions data can only be trusted if the model ensures carbon conservation. Considerable effort has been devoted to achieve this in the CONCAWE model which provides not only material balance but also elemental balance for carbon, hydrogen and sulphur. This makes it possible to “track” carbon through the refinery and evaluate not only the total carbon intake of the refineries but also the carbon that leaves the refineries in each product. Looking at the differential between two cases, one can then evaluate the total carbon effect split between the carbon emitted on site and the carbon to be emitted by the fuel products.

A further degree of sophistication is to evaluate the effect of changes in composition on the heating value of products. Indeed, as long as compositional changes of the fuels have no material impact on the energy efficiency of the final converters, demands of fuel products can be considered constant in terms of energy content rather than mass or volume. By calculating the heating value of each product based on its elemental composition, the model can keep track of small changes resulting from e.g. hydrogen addition and adjust the mass demand accordingly. Most quality changes result in an increase in hydrogen to carbon ratio leading to a higher heating value and therefore a reduction of the mass demand and of the CO_2 emissions. This CO_2 “credit” represents the fact that the hydrogen introduced in the products during refining is not “lost”. The only loss is linked to the energetic inefficiency of the refinery processes.

Notes:
Site versus overall CO_2 emissions
The objective of the model is to maximise economics, rather than minimising CO_2 emissions. In particular the model is free to vary the carbon content of the fuel burned in the refinery (as long as the maximum combined fuel sulphur content is not exceeded). In this case the average carbon content of the products is also changed so that the overall carbon balance is still respected. In certain cases, because of changes in the composition of the refinery fuel, the site CO_2 emissions from one case to another may vary for the same energy requirement.

Uncertainty
Although the model is balanced, both overall and for carbon, the complex mathematical process whereby the results are obtained leads to small accuracy losses through e.g. rounding off. Although this is of no consequence when looking at a single run, the resulting difference can become more significant when comparing two cases that are close to each other. As a result we consider that a difference in CO_2 emissions below 0.3 Mt/a is not significant.

2.7. HOW REALISTIC IS THE MODEL?

Any model, however sophisticated, remains an approximate representation of reality and results should always be viewed with this in mind. In the case of the CONCAWE EU refining model there are some areas of potential concern.

The focus on investment as the only way to meet changes seems to ignore the more complex and diverse reality where some refiners will choose trading rather than investment to solve their particular problem. It is believed, however, that, whether investment or trading is selected, the cost to the refining industry will remain more or less the same as the free-market will produce product differentials which will just support marginal investment.

Splitting Europe into regions and combining all refineries in each region could lead to some degree of over-optimisation. It must be noted, however, that as specifications tighten, few refineries bar the most complex ones can afford to operate in isolation and find it most beneficial to exchange intermediate streams and blending components with others. Also when it comes to reducing sulphur to such low figures practically every single stream needs to be treated and there is very little synergy from the simultaneous availability of a large number of blending components.

In such a generic model, it is not possible to represent the diversity of either crude oil supply or process unit configurations and yield patterns. One has to revert to generic crudes and generic process yields and product properties. The “acid test” for the model is its ability to adequately represent a known operating point of the industry, represented by a “base year”. The calibration on the year 2000 took into account the actual European crude diet and regional product make (from published sources such as the IEA) as well as the installed plant capacities as far as known (the best source of information being the Oil and Gas Journal annual survey corrected with member companies’ data). The calibration was considered successful when the model displayed its ability to produce the product demand with a realistic crude diet (expressed in simple LS/HS terms) and with only minor adjustments to the plant capacities.

Although the model gives absolute results describing the whole refining system being modelled, the results are usually expressed as differentials to the reference case. Therefore it is more important for the model to properly take into account the impact of a change rather than give an accurate representation of the absolute numbers.

The model provides a Europe-wide solution based on a global optimisation. In particular the model is free, within the constraint of a constant total crude availability, to shift crude supply between regions. One must keep this in mind when attempting to compare regional results. For instance shifting to a somewhat lighter crude diet in a given region is likely to reduce the CO_2 emissions of that region, irrespective of other requirements such a fuel specifications.

It must also be kept in mind that the model estimates the overall effect of a change. In reality each refinery will seek the most cost-effective route to address its own specific set of technical, financial and other constraints. When expressed as a percentage of the total, the increased CO_2 emissions estimated by the model should therefore only be regarded as an average. In reality there will be a large variation in the extra emissions from refineries.

3. STUDY PREMISES, CASES AND SENSITIVITY SCENARIOS

3.1. EU ROAD FUELS MARKET AND SUPPLY FROM REFINERIES

The 2010 product demands and qualities as well as crude supply have been set on the basis of the 2001 study carried out by Wood MacKenzie on behalf of the Industry.

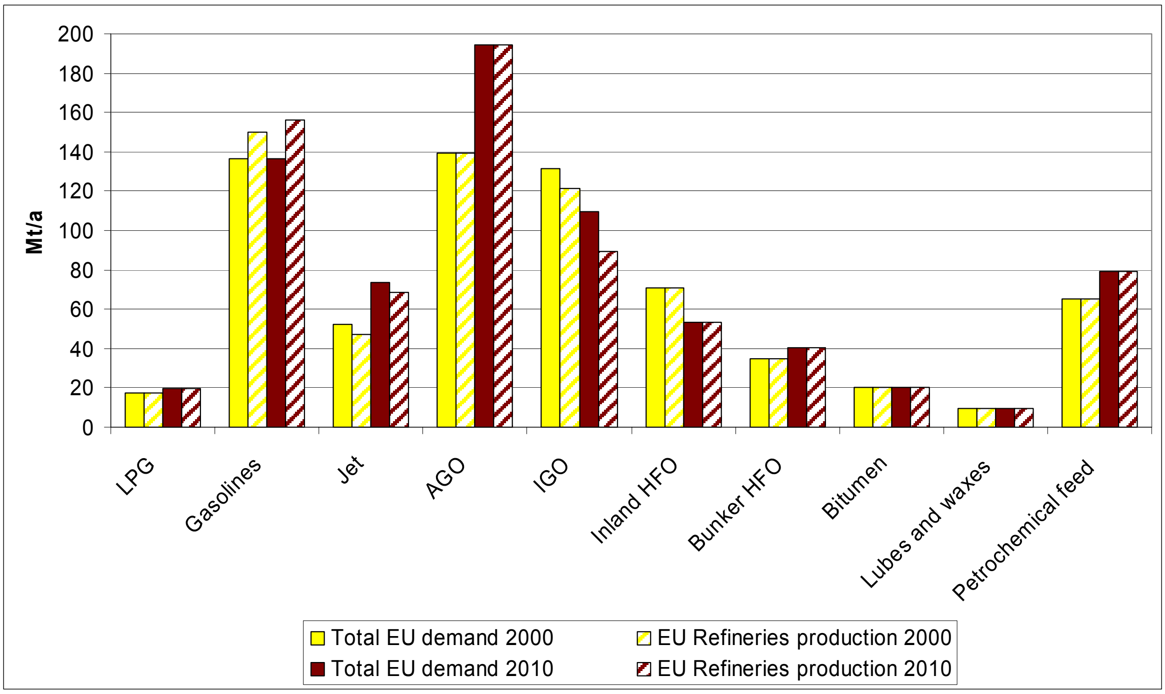
The 2000 road fuels market for the 9 regions under consideration was approximately 135 and 140 Mt for gasoline and diesel fuel respectively. Some 30% of the diesel fuel is consumed by light-duty vehicles. The share of diesel in the total transport fuel demand has been growing for a number of years and is expected to continue to do so. By 2010 diesel demand is expected to reach about 194 Mt at which time it will represent close to 60% of the total transport fuel demand. This includes a total of some 9 Mt/a of off-road diesel in those countries where it already has road diesel quality. The balance of the off-road diesel (about 13 Mt/a) is assumed to have IGO quality as is the case today (with some exceptions such as Spain where additional quality parameters apply). Gasoline demand will be more or less stable, contraction in the west being compensated by growing demand in the new EU countries.

The bulk of the market demand is supplied by the European refining industry. Because of the demand imbalance developing between gasoline and diesel and a continued increased demand for jet fuel, Europe is, however, structurally short of middle distillates and long in gasoline. In 2000 it imported a net 10 Mt of gasoils plus 5 Mt of jet fuel and exported some 13 Mt of gasoline. These figures are expected to increase to 25 Mt/a for middle distillates imports and 20 Mt/a for gasoline exports by 2010 (note that we have assumed all gasoil imports to be IGO quality).

Because of the very stringent specifications in the EU it is expected that a large fraction of the imported diesel fuel material will not meet the required quality and will need additional processing in EU refineries. We have made the conservative assumption that all additional middle distillate imports are of heating oil quality and therefore that the EU refineries will have to produce the total diesel fuel demand and most of the jet fuel demand. Gasoline exports are essentially to the USA and the quality requirements specified in the model reflect this.

The total demand in 2000 and 2010 and the portion of that demand that has to be met by European refineries are shown in **Figure 2**.

Figure 2 Total demand and supply from European refineries in 2000 and 2010



Product quality was set in accordance with the currently legislated measures for 2010 i.e. 35% v/v aromatics in gasolines, 0.1% m/m sulphur in heating oil. **For the reference case, the road fuels sulphur specification was set at 150 ppm for gasoline and 350 ppm for diesel**. This reference case represents therefore a hypothetical scenario where the 2000 sulphur specifications would still be in force in 2010. The difference between this case and the 2000 base case stems from the evolution of the demand as well as the need to meet the other specifications mentioned above.

In line with the conclusions of the Wood MacKenzie study, we have assumed that the current crude diet of just over 50% sweet crude will not have substantially changed by 2010 (although the origin of the crudes will be different, the loss of light low sulphur crudes from the North Sea being compensated by similar grades from West Africa and the Caspian Sea area). The average crude sulphur content in 2010 is close to 1% m/m. Any additional crude requirement from the reference case is, however, assumed to be covered by a heavy, high-sulphur Middle East grade.

Note that the crude diet, although an essential assumption when it comes to evaluating absolute figures, is less important for comparing two cases with both very deep levels of desulphurisation. Indeed, at the 50 ppm level the majority of components already have to be treated. Moving to 10 ppm requires deeper but little additional desulphurisation while the extra hydrogen consumption is small.

Energy consumption is, of course, crucial to the evaluation of CO_2 emissions. The overall energy consumption has been calibrated to reflect the actual figure in the 2000 case. Moving to 2010, we have assumed an annual 0.5% improvement in the global energy efficiency of EU refineries.

An overview of the feeds, product demand and specifications is given in **Appendix 2**.

3.2. ALTERNATIVE CASES

The main alternative cases are for reduction of the sulphur specification to either 50 or 10 ppm (40 or 7 in the model) for both gasoline and diesel fuel. Cases have also been run to represent sulphur reduction to 10 ppm in only either gasoline or diesel. The total differential between the reference case and the 10 ppm case gives an estimate of the total impact, in 2010, of reducing sulphur from the 2000 specifications to 10 ppm. The additional impact of other specification changes or of changes in demand during the decade is represented by the difference between the reference 2010 case and the 2000 base case. **Table 2** gives a summary of the study cases.

Table 2 Case overview

	2000	**2010**				
	Base	**Reference**	**Alternatives**			
Study Case	Gasoline 150 ppm diesel 350 ppm	Gasoline 150 ppm diesel 350 ppm	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Nominal sulphur specification (ppm)						
Gasoline	*150*	*150*	*50*	*10*	*10*	*50*
Diesel fuel	*350*	*350*	*50*	*10*	*50*	*10*
Model blending target (ppm)						
Gasoline	140	140	40	7	7	40
Diesel	340	340	40	7	40	7

3.3. SENSITIVITY SCENARIOS

As any Linear Programming model, the CONCAWE model delivers a single “optimised” solution and does not provide a view on the sensitivity of the results to various parameters. We have therefore defined a number of sensitivity scenarios dealing with those input parameters that are considered to be most critical to the outcome.

The scenario described above is referred to as the “core scenario”. We have included sensitivities on crude slate, energy consumption and the migration of all non-road diesel to road diesel specification.

3.3.1. Sensitivity scenario 1: Heavier crude slate

The crude slate has been changed to reflect a possible higher penetration of heavy, high sulphur crudes at the 2010 horizon (**Table 3**).

Table 3 Crude slates – Core and sensitivity scenarios

	Core scenario		Sensitivity scenario	
	Mt/a	%	Mt/a	%
Brent blend	333	43.9	302	39.6
Nigerian Forcados	77	10.2	77	10.1
Algerian condensate	2	0.3	2	0.3
Total LS crude	**413**	**54.3**	**381**	**50.0**
Urals (Russian export blend)	87	11.4	83	10.8
Iranian light	158	20.7	155	20.3
Kuwait (1)	102	13.5	144	18.8
Total HS crude	**347**	**45.7**	**381**	**50.0**
Total crude	**759**		**762**	

(1) Balancing crude. Figure given is for reference case

Note that the higher total crude intake in the sensitivity scenario reflects the larger energy consumption inherent in producing a constant product slate with a heavier crude diet.

3.3.2. Sensitivity scenario 2: High energy consumption for CC gasoline desulphurisation

Desulphurisation of cracked gasoline is central to achieving sulphur-free gasoline. The assumptions regarding these processes are therefore crucial. A range of processes is available and they differ in many ways, including their energy consumption and the octane penalty associated with the removal of sulphur. Our core model assumes an energy consumption figure of 0.85 GJ/t of light CC gasoline (boiling range C5-143, in two cuts) which represents an average for the various available processes. In this sensitivity scenario the energy consumption has been increased by 50%.

Within the relatively small range encountered in modern processes, the model proved rather insensitive to a change in octane loss (the core model assumes 1.0-1.5 point loss of RON and around 0.5 points of MON for the C5-143 cut).

3.3.3. Sensitivity scenario 3: Energy efficiency unchanged from 2000

The additional energy required to achieve sulphur-free fuels is obviously related to the assumed overall energy efficiency of the refineries. The model includes a global energy efficiency parameter whereby the overall energy consumption can be adjusted. In the core scenario the global energy consumption has been set to match real figures for 2000 and a 0.5% year on year global efficiency improvement has been assumed. In this sensitivity scenario we have frozen the energy efficiency at the 2000 level, thereby increasing the energy consumption in 2010 by about 5%.

3.3.4. Sensitivity scenario 4: Non-road diesel at road diesel specification

At present, the non-road diesel specification varies from country to country from IGO to road diesel quality with some countries applying intermediate specifications. The uniform requirement for the full road diesel quality would create additional requirement for desulphurisation as well as increase the pressure on other parameters such as cetane and density.

3.3.5. Sensitivity scenario 5: Combined changes

This is a worst-case energy scenario combining 1 to 4 above.

Table 4 gives an overview of all cases considered in this study.

Table 4 Scenario overview

Year	2000	2010				
Case	Base	Reference	Alternatives			
	Gasoline 150 ppm diesel 350 ppm	Gasoline 150 ppm diesel 350 ppm	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
	Core					
Scenarios 1	Heavy crude slate					
Scenarios 2	High energy for CC gasoline desulphurisation					
Scenarios 3	Overall energy efficiency unchanged from 2000					
Scenarios 4	Non-road diesel at AGO spec					
Scenarios 5	Combination of 1 to 4 above					

4. RESULTS

Each model run delivers, for each region as well as the entire area, a complete material balance, detailed quality parameters for all finished products and the composition of each product grade. Utilisation of the existing plant as well as the capacity required for new plants is also reported while the associated capital cost is calculated (according to the logic detailed in **Appendix 1**). Detailed results of each run are available within CONCAWE.

This report presents a comparison of the different alternatives with the reference case, with particular emphasis on cost, energy, CO_2 emissions and impact on product quality. More detailed results are tabulated in **Appendix 3** for the total EU as well as for individual regions.

This section presents and discusses the results for the core scenario with, where appropriate, the range of variation resulting from the sensitivity scenarios. Details for each scenario are also available in **Appendix 3**.

4.1. ADDITIONAL PLANT CAPACITY AND INVESTMENT COST

The bulk of the new process plant capacity required to reduce sulphur in transport fuels is associated with the process units described in **Sections 2.3** and **2.4** above. These account for over 80% of the investment cost. The model also accounts for secondary effects mostly associated with recovery of the octane loss and more generally with the need to meet demand. **Table 5** shows the new capacities for the key plants and the associated capex.

Table 5 New installed capacity of key process units and associated CAPEX (total Europe)

		Capacity Mt/a					Capex M€				
	Sulphur specification (ppm)	Gasoline 150 ppm Diesel 350 ppm	Transport 50 ppm	Transport 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Gasoline 150 ppm Diesel 350 ppm	Transport 50 ppm	Transport 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
	Gasoline	*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
	Diesel	*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
		New from 2000	New, additional to reference				New from 2000	New, additional to reference			
Gasoline-related	Cracked gasoline splitter	**R** 7.1	7.6	21.7	21.9	6.5	**R** 66	78	208	210	68
	Naph HT	**e**					**e**				
	Cracked gasoline HT	**f** -0.2	9.0	23.6	24.2	8.3	**f** -17	675	1713	1754	623
	Cracked gasoline sweetening	**e** 0.7	0.1	1.8	2.2	0.1	**e** 39	7	110	134	8
	Cat reforming (LP)	**r**	1.1	2.7	2.6	1.2	**r**	149	351	333	168
	Reformate splitter	**e** 3.4	0.1	-0.5	-0.5	0.7	**e** 77	-4	-19	-20	16
	Light reformate splitter	**n** 0.9	0.2	0.4	0.4	0.2	**n** 26	5	11	10	5
	Alkylation	**c** 0.2	0.0	0.1	0.1	0.0	**c** 53	-1	33	33	-6
	Isomerisation once-through	**e** 0.2	-0.1	0.0	0.0	-0.1	**e** 34	-8	-1	-2	-12
	Isomerisation recycle			0.5	0.5				97	102	
	MTBE	0.5	0.1	0.1	0.1	0.1	235	54	51	52	49
	TAME	0.7	-0.1	0.2	0.2	0.1	107	-12	29	30	15
Diesel-related	Kero HT	25.1	1.8	4.9	1.3	5.1	1109	77	198	56	204
	GO HT LP										
	GO HT MP revamp						510	252	318	261	318
	GO HT HP	14.5	15.3	37.7	16.0	36.9	1129	1170	2857	1222	2796
	GO HDA										
	Hydrogen manuf (as hydrogen) [(1)]	*159*	*40*	*90*	*56*	*73*	277	69	154	96	125
	Hydrogen scavenging [(1)]	*9*	*10*	*41*	*25*	*15*	12	13	55	33	20
	Total [(2)] Core scenario						**7318**	**2892**	**6733**	**4816**	**4774**
	Total for sensitivity scenarios										
	1: Heavier crude slate (5% shift towarsd heavy crude)						8765	3060	6912	5124	4970
	2: 50% higher energy consumption for FCC gasoline desulphurisation						7375	2959	6755	4856	4762
	3: Energy efficiency unchanged from 2000						7392	2776	6550	4722	4573
	4: Non-road diesel at AGO spc						7552	3056	7264	5057	5310
	5: Combined changes						8781	3536	7545	5571	5782

(1) Capacities expressed in kt/a

(2) Including all units

Note: Figures for all cases beyond the reference case are shown as differential to the reference case. As a result figures from the gasoline 10 ppm and diesel 10 ppm cases cannot be added as they both include the path from 150/350 to 50 ppm for gasoline and diesel.

> *Sulphur reduction of road fuels beyond the 2000 specifications requires refinery capex of 2.9 to 3.5 G€ to 50 ppm sulphur and 6.7 to 7.5 G€ to 10 ppm. Gasoline and diesel equally share the difference of about 4 G€ between the two target limits.*
>
> *These investment figures are in addition to another 7.3 G€ required to meet the evolution of demand and the changes to other specifications between 2000 and 2010. This figure would rise to nearly 8.8 G€ with a heavier crude slate.*

For gasoline the investment occurs as a combination of a range of process units aiming at removing sulphur from cracked gasoline in the most efficient manner and with minimum loss of octane. Additional investment is also required to compensate for the inevitable octane loss.

For diesel fuel investment is essentially in hydrodesulphurisation plants designed to deeply desulphurise all diesel blending components.

The above figures are only marginally affected in the sensitivity scenarios, with the exception of the 2000-2010 capex which increases significantly (to nearly 8.8 M€) with the heavier crude slate.

4.2. CO_2 EMISSIONS

Table 6 and **Figure 3** summarise the changes in CO_2 emissions.

Table 6 CO_2 emissions (total Europe), Mt/a

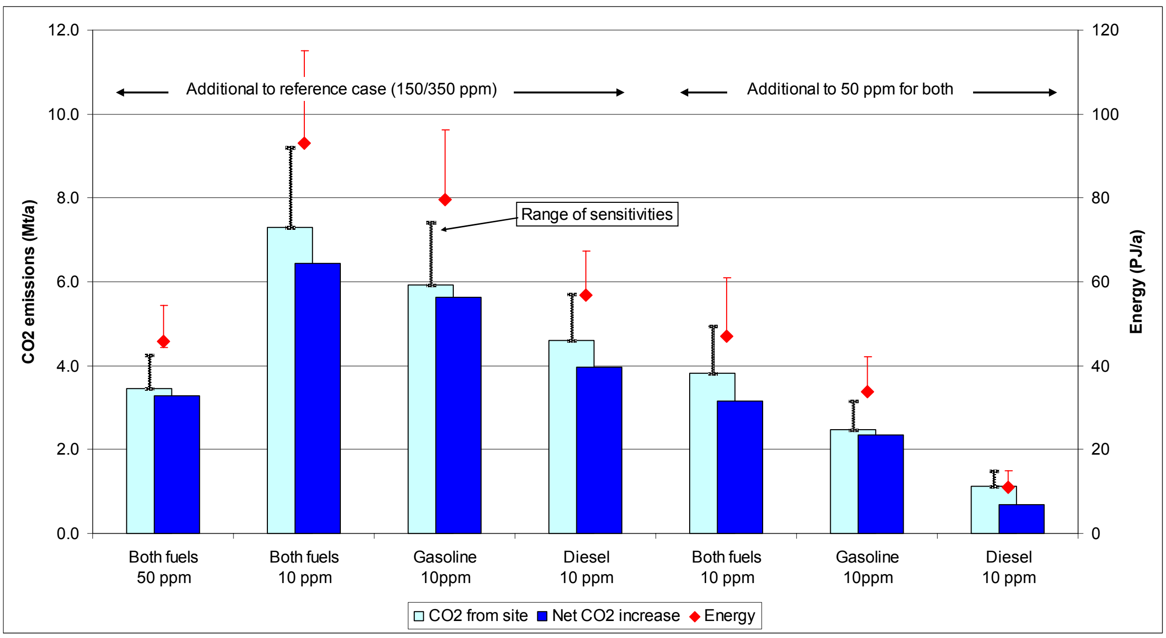
	2000	2010								
	Base	Reference	Alternatives							
	Gasoline 150 ppm diesel 350 ppm	Gasoline 150 ppm diesel 350 ppm	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Sulphur specification (ppm)									
Gasoline	*150*	*150*	*50*	*10*	*10*	*50*	*10*	*10*	*50*
Diesel fuel	*350*	*350*	*50*	*10*	*50*	*10*	*10*	*50*	*10*
Core scenario	Add to ref	Total	Additional to reference				Additional to 50ppm for both fuels		
From site	**-13.3**	**154.5 (*)**	**3.5**	**7.3**	**5.9**	**4.6**	**3.8**	**2.5**	**1.1**
From fuel products		2028.3	-0.2	-0.8	-0.3	-0.6	-0.7	-0.1	-0.4
From import/export		-11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net		2017.0	3.3	6.4	5.6	4.0	3.2	2.3	0.7
Sensitivity scenarios									
From site									
Sensitivity 1[1]	-19.1	160.3	3.6	7.6	6.4	5.0	4.1	2.9	1.4
Sensitivity 2	-13.3	154.5	3.5	7.9	6.5	4.7	4.4	3.0	1.3
Sensitivity 3	-20.5	161.7	3.5	7.7	6.2	4.9	4.2	2.7	1.4
Sensitivity 4	-13.4	154.6	3.8	8.2	6.5	5.3	4.3	2.7	1.5
Sensitivity 5	-26.8	168.0	4.3	9.2	7.4	5.7	5.0	3.2	1.4
Range from sensitivities									
From site	**-26.8 _ -13.3**	**154.5 - 168**	**3.5 - 4.3**	**7.3 - 9.2**	**5.9 - 7.4**	**4.6 - 5.7**	**3.8 - 5**	**2.5 - 3.2**	**1.1 - 1.5**
Net		2017 - 2185	3.2 - 3.9	6.4 - 8.2	5.6 - 7	4 - 4.8	3.2 - 4.3	2.3 - 3.1	0.7 - 0.9
Production for EU market to sulphur spec [2] (Mt/a)									
Gasoline			*123.3*	*123.2*			*123.2*	*123.2*	
Diesel fuel			*182.6*	*182.5*			*182.5*		*182.4*
kg CO_2 per tonne of fuel	kg/t		**11.3**	**23.8**			**12.5**	**20.0**	**6.2**

(*)138 when excluding petrochemicals

[1] Sensitivities
1: Heavier crude slate (5% shift towards heavy crude)
2: 50% higher energy consumption for FCC gasoline desulphurisation
3: Energy efficiency unchanged from 2000
4: Non-road diesel at AGO spec
5: Combined changes

[2] Excluding Eastern and export grades

Figure 3 Refinery CO_2 emissions and energy consumption (total Europe)



Sulphur reduction of road fuels beyond the 2000 specifications causes the EU refineries to emit an additional amount of CO_2 of 3.5 to 4.3 Mt/a to 50 ppm sulphur and 7.3 to 9.2 Mt/a to 10 ppm. Gasoline is responsible for 65% and diesel fuel for 35% of the difference of 4 to 5 Mt/a between the two target limits.

In order to cope with demand evolution and with the changes in other specifications between 2000 and 2010, EU refineries will further increase their CO_2 emissions by 13.3 Mt/a, increasing to 26.8 Mt/a in the worst scenario considered.

The reduction of the carbon content of fuel products contributes to a potential reduction of global CO_2 emissions when the fuels are burned of about 0.2 Mt/a at 50 ppm and 0.8 Mt/a at 10 ppm.

Changing all EU non-road diesel to road diesel quality would increase CO_2 emissions by nearly 1 Mt/a. This would be principally borne by those countries that have a large non-road fuel market and where the specification is currently that of IGO (principally France).

Note that out of the total CO_2 emissions figure of 154.5 Mt/a (core case) about 16.5 Mt/a comes from steam crackers. The CO_2 emissions estimate for the purely refining sector is therefore in the order of 138 Mt/a.

4.3. OVERALL COST

Beside the investment cost, reduction of fuel sulphur brings additional operating costs:

- Additional energy is used,
- The new plants need to be operated and maintained,
- Additional CO_2 is emitted which, in the near future will attract a cost (we have assumed a figure of 20 €/t).

In **Table 7** we have expressed the total cost as:

- an annualised cost (using a capital charge of 15% of capex per annum),
- a Net Present Value (NPV according to the definition used in Auto-Oil 2)
- a cost per tonne of the total gasoline and/or diesel quantity that has been submitted to the additional desulphurisation.

Table 7 Overall cost from reference case (total Europe)

		Additional to reference (150/350 ppm)				Additional to 50ppm for both fuels		
		Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Sulphur specification (ppm)								
Gasoline		*50*	*10*	*10*	*50*	*10*	*10*	*50*
Diesel		*50*	*10*	*50*	*10*	*10*	*50*	*10*
Core scenario								
Capital Investment	M€	**2892**	**6733**	**4816**	**4774**	**3841**	**1923**	**1882**
Capital Charge @15%		434	1010	722	716	576	289	282
Opex	M€/a	**260**	**586**	**402**	**449**	**326**	**142**	**189**
Of which CO_2 emissions		69	146	119	92	76	49	23
Margin loss [1]		**148**	**292**	**256**	**178**	**144**	**108**	**30**
Annualised costs M€	M€/a	**842**	**1888**	**1381**	**1343**	**1046**	**538**	**501**
NPV [2]	G€	**6.9**	**15.3**	**11.2**	**10.9**	**8.4**	**4.4**	**4.0**
Production for EU market to sulphur spec [3]	*Mt/a*							
Gasoline		*123.3*	*123.2*			*123.2*	*123.2*	
Diesel fuel		*182.6*	*182.5*			*182.5*		*182.4*
Cost per tonne of Mogas/Diesel	€/t	**2.8**	**6.2**			**3.4**	**4.4**	**2.7**
Sensitivity scenarios								
Annualised costs M€	M€/a							
Sensitivity 1[4]		778	1824	1373	1246	1046	595	468
Sensitivity 2		778	1851	1373	1249	1072	594	470
Sensitivity 3		764	1818	1346	1236	1054	582	472
Sensitivity 4		832	1967	1414	1378	1136	582	546
Sensitivity 5		892	2048	1504	1441	1156	612	549

[1] Mainly due to additional Fuel & Loss
[2] According to Auto-Oil 2 methodology i.e. capex + 9.75 x Opex
[3] Excluding Eastern and export grades
[4]Sensitivities
1: Heavier crude slate (5% shift towarsd heavy crude)
2: 50% higher energy consumption for FCC gasoline desulphurisation
3: Energy efficiency unchanged from 2000
4: Non-road diesel at AGO spec
5: Combined changes

Sulphur reduction of road fuels beyond the 2000 specifications increases the annualised costs to EU refineries by 0.8 to 0.9 G€/a to 50 ppm sulphur and 1.8 to over 2 G€/a to 10 ppm. Gasoline is responsible for just over half of the difference of 1.1 G€/a between the two target limits, the balance being attributable to diesel.

Expressed per tonne of low sulphur fuel produced the figures are around 2.8 €/t to 50 ppm and 6.2 €/t to 10 ppm.

Servicing the capex represents over half of the total annual cost. The balance comes from margin loss, essentially in the form of additional fuel consumption, and additional operating cost of new units. The notional cost figures shown for CO_2 suggest that this element could become significant if CO_2 costs increased beyond the 10-20 €/t mark.

4.4. EU AVERAGE VERSUS INDIVIDUAL REFINERY

The figures presented so far relate to Europe as a whole. However they hide a variety of specific refinery situations and should not be used to establish a reference for e.g. increased CO_2 emissions as a percentage of the current figure.

This can be particularly well illustrated for desulphurisation of gasoline with the following example. Virtually the only gasoline components that have high sulphur content are cat cracked gasoline cuts. A refinery with a large FCC will naturally blend a high percentage of such cuts in its gasoline grades and will therefore incur a large energy penalty for desulphurisation. On the opposite end of the spectrum, a hydrocracking refinery will have no high sulphur component. In order to meet other specifications, notably maximum aromatics, it may have to import cat cracked gasoline from other refineries but the chance is that these cuts will have already been desulphurised. The hydrocracking refinery would then incur additional cost (premium for desulphurised imports) but would not increase its CO_2 emissions.

The inspection of the figures generated by the model for the various regions offer another illustration of this point. The following table shows the increase in CO_2 emissions expressed as a percentage of the starting figure for the change from the reference case to 10 ppm (both fuels) and for 50 to 10 ppm.

	Reference to 10 ppm	50 to 10 ppm
All units		
Total Europe	**4.7%**	**2.4%**
mini regional	2.0%	0.8%
Maxi regional	10.0%	5.7%
Excluding petrochemicals		
Total Europe	**5.3%**	**2.7%**
mini regional	2.2%	0.6%
Maxi regional	10.7%	6.5%

The figures vary by a factor of up to 10 between regions. There are many reasons for this including the demand pattern and refinery configuration of each region. Although the total crude slate is fixed and because the model optimises the total of Europe, there are small changes in regional crude slate between cases that also contribute to variations in CO_2 emissions. Such changes may well happen in reality as the industry finds a new balance of regional crude supply.

4.5. BLENDED PRODUCT QUALITY

The main quality parameters of the average gasoline and diesel fuel pools (excluding gasoline exports and the non-EU diesel grade) are shown in **Table 8**.

Table 8 Gasoline and diesel fuel quality changes

		2000	2010				
		Base	Reference	Alternatives			
		Gasoline 150 ppm diesel 350 ppm	Gasoline 150 ppm diesel 350 ppm	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Sulphur specification (ppm)							
Gasoline		*150*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*350*	*50*	*10*	*50*	*10*
		Gasoline (@ EU spec)					
Production	*Mt/a*	*120.6*	*123.0*	*123.3*	*123.2*	*123.2*	*123.3*
Density		0.750	0.747	0.747	0.745	0.745	0.748
Sulphur	ppm	140	124	40	7	7	40
Olefins	% v/v	14.3	14.7	13.6	10.2	10.3	13.6
Aromatics	% v/v	35.5	32.7	32.9	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.6	0.7	0.8	0.7	0.7	0.8
RON		95.5	95.4	95.3	95.3	95.3	95.3
MON		85.4	85.3	85.4	85.5	85.5	85.4
LHV	GJ/t	43.1	43.1	43.0	43.1	43.1	43.0
		AGO (@ EU spec)					
Production	*Mt/a*	*128.2*	*182.9*	*182.6*	*182.5*	*182.6*	*182.5*
Density		0.831	0.840	0.837	0.831	0.836	0.832
Sulphur	ppm	340	340	40	7	40	7
Cloud pt	°C	-10.6	-7.1	-6.5	-8.3	-6.7	-8.2
CN Ind		49.0	49.1	49.7	50.3	49.6	50.3
LHV	GJ/t	43.4	43.3	43.4	43.4	43.4	43.4

The state-of-the-art desulphurisation processes are increasingly selective towards sulphur and therefore have a relatively limited impact on other properties.

For gasoline there is a small reduction of olefins. There is also a minor impact on octane rating, with a small reduction in the difference between RON and MON, whereby RON becomes the constraining parameter. This is consistent with a gasoline that has lower aromatics, lower olefins and therefore where more of the octane comes from low sensitivity paraffinic components.

For diesel fuel density decreases somewhat while cetane index increases marginally.

Note on cetane:
The cetane rating of diesel fuels is typically estimated via one of the cetane index correlations developed for this purpose. For diesel blends the so-called "4-point method" (ASTM D4737) is preferred. Beside the density, this correlation relies on three points of the distillation curve. These data cannot be satisfactorily estimated in a model. In addition a linear model must be able to arrive at the properties of a blended product using the properties of the individual components and appropriate linear blending rules.

We have therefore opted for a more empirical method. The cetane index (CI) of virgin as well as cracked kerosenes and gasoils is estimated from their density and 50% ASTM point with the ASTM D976 correlation. A cetane gain, based on practical experience, is applied through hydrotreating on the basis of the gasoil type and the severity of the operation. The model blends cetane indices by volume.

The CI obtained for the final diesel blend should therefore be considered as an indicator of the cetane rating rather than a faithful representation of the actual cetane number. Market surveys carried out by CONCAWE have shown that the cetane number specification is not always constraining in European blends, the constraints being stronger in the north because of cloud point limitations. On this basis we have "translated" the EN 590 specification of 51 cetane into 49 CI in the model, which corresponds to a similar constraint profile.

5. COMPARISON WITH CONCAWE REPORT 00/54

In 2000 CONCAWE carried out a similar study which pointed to higher costs as well as a significantly higher CO_2 impact [1]. As a trend, this should come as no surprise as advances in technology over the last 4 years have lowered investment, hydrogen demand and energy consumption. Past and present figures need, however, to be compared in detail and the differences rationalised.

The 2000 study considered only EU-15 whereas this study includes all new EU members plus Norway and Switzerland as well as prospective Eastern European members. EU-15 figures must therefore first be extracted from the new study before a fair comparison can be done (in the new study it is not practical to separate Norway and Switzerland from EU-15 data but the impact is small). **Tables 9** to **11** compare the costs and CO_2 emission figures on this common basis.

Table 9 Comparison of costs between 2000 and current study (EU-15 basis)

NPV [1] (G€)	**Additional to reference (150/350 ppm)**		**Additional to 50 ppm for both fuels**		
	Both fuels 50 ppm	Both fuels 10 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Sulphur specification (ppm)					
Gasoline	*50*	*10*	*10*	*10*	*50*
Diesel	*50*	*10*	*10*	*50*	*10*
This study	**7.1**	**14.4**	**7.3**	**3.3**	**3.2**
2000 study	*11.7*	*24.5*	*12.8*	*5.5*	*7.1*

[1] According to Auto-Oil 2 methodology i.e. capex + 9.75 x opex

Table 10 Comparison of site CO_2 emission increase between 2000 and current study (EU-15 basis)

CO_2 emissions increase (Mt/a)	**Additional to reference (150/350 ppm)**		**Additional to 50ppm for both fuels**		
	Both fuels 50 ppm	Both fuels 10 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Sulphur specification (ppm)					
Gasoline	*50*	*10*	*10*	*10*	*50*
Diesel fuel	*50*	*10*	*10*	*50*	*10*
This study	**3 - 3.4**	**6.8 - 7.6**	**3.6 - 4.4**	**2.4 - 3**	**1.1 - 1.4**
2000 study	*6.4*	*12.6*	*6.2*	*4.0*	*1.8*

Table 11 Detailed comparison between 2000 and current study - 50 to 10 ppm for both fuels

		2000 study (EU-15)	This study (EU-15+2) Core scenario
Production	Mt/a		
Mogas		**141**	**135**
Diesel		**155**	**173**
Cost			
Capex	G€	**5.34**	**3.60**
Capital charge	G€/a	0.80	0.54
Opex	G€/a	**1.50**	**0.92**
	€/t fuel	**5.1**	**3.0**
AO II NPV	G€	**12.8**	**7.3**
CO_2 emissions	Mt/a		
Emissions from refinery sites			
CO2 ex refinery fuel		5.2	3.4
CO2 ex hydrogen production		1.0	0.4
Total site emissions		**6.2**	**3.8**
Delta site emissions			**2.4**
made up of:			
Reduction due to change in refinery fuel			1.8
Reduction of "chemical" CO_2 from hydrogen production			0.6
Global emissions			
Off-site MeOH		0.3	0.0
From fuel products			-0.6
Total global emissions		**6.5**	**3.2**

The capex is 30% lower in the new study. For diesel the reduction is attributable to the large improvements in catalyst performance whereby existing units can be revamped to a much greater extent than was previously thought possible. The picture is more complex for gasoline as the processing scheme envisaged has significantly changed. The processes now being used are addressing the problem of desulphurisation much more directly.

In line with the capex reduction, there is a corresponding reduction in operating costs. The energy requirement and therefore the additional energy cost is reduced as a result of more streamlined and efficient processing. Experience with lubricity additive has shown that only a marginal increase in dosage rate will be required at the 10 ppm level compared to the 50 ppm case.

Overall the costs are reduced by about one third.

There is a similar reduction in CO_2 emissions. Most of the difference comes from lower refinery fuel consumption and a smaller amount from lower hydrogen production. The fuel consumption related to hydrogen production in the 2000 study was overestimated. This resulted in the related CO_2 emissions being overstated by about 0.4 Mt/a. The real effect of technology improvement is therefore a reduction of CO_2 emissions by around 1.4 Mt/a due to lower fuel consumption and 0.6 Mt/a of the “chemical” CO_2 associated to the methane steam reforming reaction.

When considering the global impact, the new model, being carbon balanced, allows us to estimate the difference in CO_2 emissions when burning the fuel products, thus taking into account the changes in their chemical composition (-0.6 Mt/a). There is also a reduction related to the methanol consumption (for MTBE production). This was higher in the 2000 study. Further the CO_2 associated with methanol production has been revised downwards.

Overall the reduction of about one third of the cost and CO_2 emissions compared to the 2000 study appears in line with the limited experience in the field and the expectations from the processes being put in place to produce sulphur-free fuels.

6. REFERENCES

1. CONCAWE (2000) Impact of a 10 ppm sulphur specification for transport fuels on the EU refining industry. Report No. 00/54. Brussels: CONCAWE

2. CONCAWE (1999) EU oil refining industry costs of changing gasoline and diesel fuel characteristics. Report No. 99/56. Brussels: CONCAWE

APPENDIX 1: COST OF NEW PLANTS AND INVESTMENT COST ESTIMATION

The following capex figures have been used for the key new plants used in this study (figures are in M€ of 2004 and are meant to include both ISBL and OSBL costs. They are viewed as typical and do not take account of local or short term variations in e.g. material cost).

Plant	Capex (M€)	Capacity (Mt/a)
Gasoline-related		
CC gasoline splitter	5	0.65
CC gasoline selective hydrotreatment	40	0.70
Extractive sweetening	10	0.21
Isomerisation		0.22
Once-through	25	
Recycle	40	
Diesel-related		
Kerosene hydrotreater	30	0.90
HP gasoil HDS	75	1.30
Gasoil hydro de-aromatisation (HDA)	60	1.30
Hydrogen manufacturing (natural gas)	50	0.04

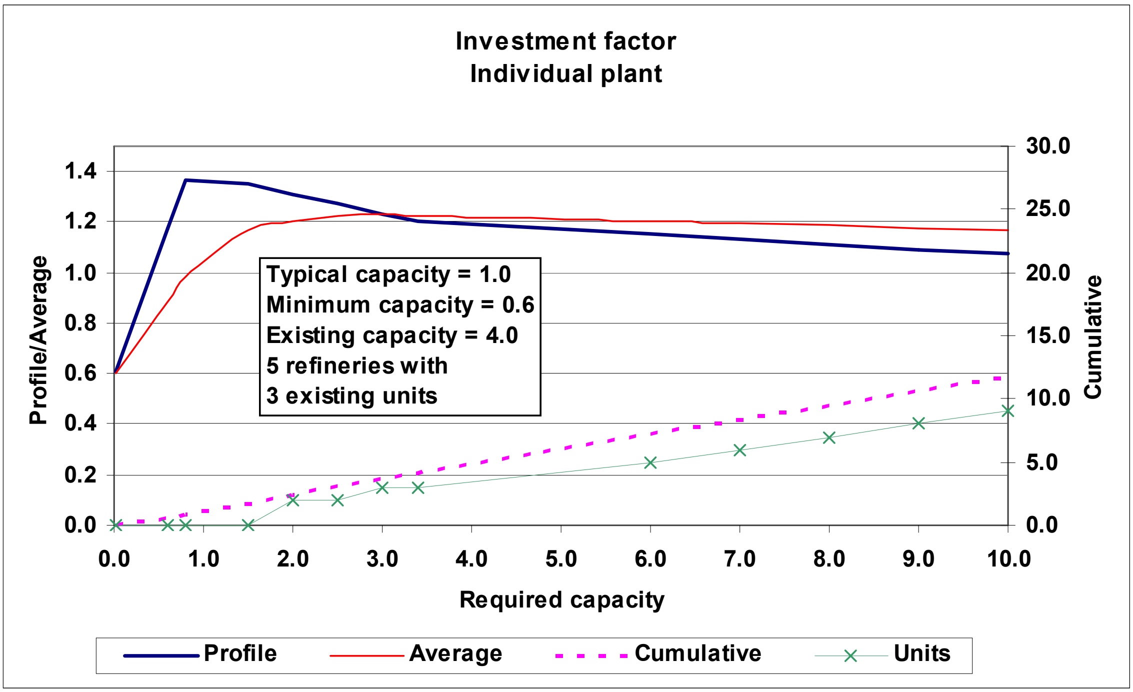
These costs are not substantially different from the ones used in the 2000 study.

The model produces a required additional capacity for each process unit in each refinery/region. This needs to be translated into a plausible investment cost based on the cost of a typical unit and the number of actual units that might be required (inasmuch as smaller units will cost relatively more per unit capacity).

The logic we use first considers whether the type of unit is likely to be installed by every refinery or “shared” amongst refineries via e.g. processing deals. For example a gasoil HDS could not conceivably be shared whereas a hydrocracker might be. “Shared” units will tend to have larger capacities and will therefore better benefit from economies of scale.

We then consider that any existing unit of this type will have a potential for revamp, starting at a lower cost per t of capacity than a new unit. As the required capacity increases, the unit revamp cost increase until it reaches the cost corresponding to the minimum practical capacity for this type of plant. After this the unit cost slowly decreases towards that of the typical plant above.

The figure below gives an example of investment profile for a non-shared plant with a typical capacity of 1.0 Mt/a, a minimum of 0.6 Mt/a, 4.0 Mt/a of already installed (existing) capacity). The curves refer to a case where there are 5 refineries in the region, 3 of which having already one such plant.



APPENDIX 2: FEEDS, PRODUCT DEMAND AND SPECIFICATIONS

Crude supply

	Core scenario	
	Mt/a	%
Brent blend	333	43.9
Nigerian Forcados	77	10.2
Algerian condensate	2	0.3
Total LS crude	**413**	**54.3**
Urals (Russian export blend)	87	11.4
Iranian light	158	20.7
Kuwait [(1)]	102	13.5
Total HS crude	**347**	**45.7**
Total crude	**759**	

[(1)] Balancing crude. Figure given is for reference case

Product specifications and model quality target

<table>
<tr><th colspan="3">Gasoline</th><th>UL92</th><th>UL95</th><th>UL98</th><th>Eastern grade [(1)]</th><th>Export</th><th>Delta to model target</th></tr>
<tr><td>Density</td><td>kg/m³</td><td>Max</td><td colspan="5">775</td><td></td></tr>
<tr><td></td><td></td><td>min</td><td colspan="5">725</td><td></td></tr>
<tr><td>Sulphur</td><td>ppm m</td><td>Max</td><td colspan="3">As per study case</td><td>400</td><td>80</td><td>[(2)]</td></tr>
<tr><td>RON</td><td></td><td>min</td><td>92</td><td>95</td><td>98</td><td>94</td><td>93</td><td>0.3</td></tr>
<tr><td>MON</td><td></td><td>min</td><td>82</td><td>85</td><td>88</td><td>84</td><td>83</td><td></td></tr>
<tr><td>Olefins</td><td>% v/v</td><td>Max</td><td colspan="3">18.0</td><td></td><td>10</td><td>-1.0</td></tr>
<tr><td>Aromatics</td><td>% v/v</td><td>Max</td><td colspan="3">35.0</td><td></td><td></td><td>-2.0</td></tr>
<tr><td>Benzene</td><td>% v/v</td><td>Max</td><td colspan="3">1.0</td><td>2.5</td><td></td><td>-0.1</td></tr>
<tr><td>Oxygen</td><td>% v/v</td><td>Max</td><td colspan="4">2.7</td><td>2.3</td><td></td></tr>
<tr><td>VP</td><td>kPa</td><td>Max</td><td colspan="4">70</td><td>58</td><td></td></tr>
<tr><td>E70</td><td>% v/v</td><td>Max</td><td colspan="5">45</td><td></td></tr>
<tr><td></td><td></td><td>min</td><td colspan="5">20</td><td></td></tr>
<tr><td>E100</td><td>% v/v</td><td>Max</td><td colspan="5">65</td><td></td></tr>
<tr><td></td><td></td><td>min</td><td colspan="5">47</td><td></td></tr>
<tr><th colspan="3">Diesel</th><th colspan="3">EU grades</th><th>Eastern grade [(1)]</th><th></th><th>Delta to model target</th></tr>
<tr><td>Density</td><td>kg/m³</td><td>Max</td><td colspan="3">845</td><td>860</td><td></td><td>-5</td></tr>
<tr><td></td><td></td><td>min</td><td colspan="3">820</td><td>800</td><td></td><td></td></tr>
<tr><td>Sulphur</td><td>ppm m</td><td>Max</td><td colspan="3">As per study case</td><td>3000</td><td></td><td>[(2)]</td></tr>
<tr><td>Cetane index</td><td></td><td>min</td><td colspan="4">49[(3)]</td><td></td><td></td></tr>
<tr><td>PAH</td><td>% m/m</td><td></td><td colspan="4">11</td><td></td><td></td></tr>
<tr><td>Cloud point</td><td>°C</td><td>Max</td><td colspan="4">[(4)]</td><td></td><td></td></tr>
</table>

[(1)] Only for SEU region

[(2)] 150/350 ppm: -10, 50 ppm: -10, 10 ppm: -3

[(3)] Empirical representation of cetane rating. Value consistent with current 46 CI / 51 CN specification

[(4)] from 0 to -7.5 depending on region

Call on refineries (reference case; gasoline at 150 ppm S, diesel at 350 ppm) (Core scenario)

All figures in Mt/a

2010	Total Europe	SCA	UKI	BEN	MEU	FRA	IBE	ITG	EEU	SEU
LPG	19.6	2.1	2.4	1.7	1.7	3.5	2.7	2.8	1.7	1.0
Gasolines	156.2	9.8	24.0	14.7	26.5	19.4	14.3	26.2	10.6	10.7
Reg 92	*4.3*	*0.0*	*0.0*	*0.0*	*4.0*	*0.0*	*0.0*	*0.4*	*0.0*	*0.0*
Super 95	*112.1*	*8.9*	*22.0*	*10.9*	*21.1*	*10.6*	*8.9*	*19.1*	*10.6*	*0.0*
Prem 98	*6.6*	*0.0*	*0.0*	*0.0*	*1.4*	*3.6*	*1.6*	*0.0*	*0.0*	*0.0*
East	*13.3*	*0.0*	*0.0*	*2.1*	*0.0*	*0.0*	*0.0*	*0.6*	*0.0*	*10.7*
Export	*19.8*	*1.0*	*2.0*	*1.7*	*0.0*	*5.2*	*3.8*	*6.2*	*0.0*	*0.0*
Jet	68.8	4.2	13.2	10.2	13.3	9.8	7.9	8.2	1.5	0.6
AGO	194.6	11.0	23.3	22.7	33.3	20.9	27.1	35.3	8.8	12.3
North	*15.5*	*11.0*	*0.0*	*0.0*	*4.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Middle	*89.0*	*0.0*	*23.3*	*22.7*	*28.8*	*5.3*	*0.0*	*0.0*	*8.8*	*0.0*
South	*78.5*	*0.0*	*0.0*	*0.0*	*0.0*	*15.6*	*27.1*	*34.6*	*0.0*	*1.2*
East	*11.7*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.7*	*0.0*	*11.0*
IGO	89.6	11.2	4.9	9.7	18.6	14.0	5.7	12.3	10.1	3.0
North	*11.9*	*9.6*	*0.0*	*0.0*	*2.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Middle	*40.5*	*0.0*	*3.1*	*5.8*	*14.4*	*7.2*	*0.0*	*0.0*	*10.1*	*0.0*
South	*34.4*	*1.6*	*1.8*	*4.0*	*2.0*	*6.8*	*5.7*	*11.9*	*0.0*	*0.7*
East	*2.8*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.4*	*0.0*	*2.3*
Inland HFO	53.5	4.4	7.5	2.0	5.9	7.9	5.2	9.6	4.4	6.6
VLS HFO	*0.6*	*0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
LS HFO	*45.3*	*3.8*	*7.5*	*2.0*	*5.9*	*7.9*	*5.2*	*8.4*	*4.4*	*0.2*
MS HFO	*0.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.4*	*0.0*	*0.0*
HS HFO	*7.2*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.8*	*0.0*	*6.4*
Bunker HFO	40.5	2.8	2.0	15.9	4.9	2.8	6.4	5.3	0.4	0.0
LS Bunker	*13.0*	*2.8*	*0.6*	*7.9*	*1.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
HS Bunker	*27.5*	*0.0*	*1.4*	*8.0*	*3.2*	*2.8*	*6.4*	*5.3*	*0.4*	*0.0*
Bitumen	20.3	0.3	2.2	0.7	4.3	3.7	2.7	2.9	2.8	0.7
Lubes and waxes	9.6	0.3	0.9	1.1	2.0	1.4	1.1	1.1	1.3	0.3
Petrochemical feed	79.4	4.2	4.6	16.3	17.5	11.6	6.1	11.9	4.0	3.1

Material balance (reference case; gasoline at 150 ppm S, diesel at 350 ppm) (Core scenario)

All figures in Mt/a

	Total	SCA	UKI	BEN	MEU	FRA	IBE	ITG	EEU	SEU
In										
Crude	759.48	51.46	95.30	95.95	123.03	94.59	84.58	126.17	46.99	41.41
LS	412.50	38.53	74.76	54.64	65.03	59.10	46.31	54.30	19.11	0.71
HS	346.97	12.93	20.54	41.30	58.00	35.49	38.26	71.87	27.88	40.70
Other feeds and components										
Naphthas and mogas comp	12.22	1.97	0.00	1.82	3.69	3.82	0.00	0.00	0.11	0.80
Gasoils	3.65	0.00	0.00	0.00	3.65	0.00	0.00	0.00	0.00	0.00
Cracker feed	4.07	0.00	2.65	1.00	0.42	0.00	0.00	0.00	0.00	0.00
Methanol	1.03	0.07	0.21	0.10	0.00	0.17	0.12	0.18	0.08	0.10
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE	2.10	0.00	0.56	0.00	0.00	0.12	0.33	1.09	0.00	0.00
ETBE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethane	2.50	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nat gas	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.68	0.00	0.00	0.05	0.42	0.02	0.04	0.12	0.04	0.00
Out										
Main products										
LPG	19.56	2.07	2.44	1.71	1.67	3.47	2.74	2.83	1.67	0.95
Gasolines	156.18	9.84	24.02	14.65	26.47	19.37	14.33	26.23	10.60	10.67
Jet	68.77	4.16	13.17	10.24	13.27	9.76	7.88	8.19	1.50	0.59
AGO	194.62	11.02	23.34	22.69	33.27	20.91	27.09	35.27	8.79	12.25
IGO + gasoil comp.	92.60	11.23	6.98	9.73	18.59	14.03	5.66	13.28	10.08	3.03
LSFO	58.88	7.26	8.08	9.89	7.54	7.86	5.24	8.40	4.39	0.22
HSFO	35.13	0.00	1.44	7.98	3.23	2.82	6.41	6.47	0.36	6.42
Bitumen	20.26	0.31	2.15	0.70	4.28	3.74	2.67	2.93	2.77	0.71
Lubs and waxes	9.56	0.31	0.91	1.12	2.03	1.42	1.05	1.06	1.32	0.34
Coke	3.85	0.33	0.59	0.49	1.28	0.00	0.56	0.61	0.00	0.00
Electricity (TWh/a)	24.00	0.00	5.00	0.00	1.50	0.00	0.00	10.00	5.00	2.50
Petrochemicals										
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	26.70	1.42	2.65	5.27	5.72	3.65	1.99	3.71	1.30	1.01
Propylene	17.96	1.04	1.40	3.16	3.69	2.67	1.52	2.63	0.91	0.94
C4 olefins	2.94	0.00	0.21	0.46	0.94	0.48	0.24	0.36	0.15	0.10
Benzene	9.88	0.59	0.88	1.99	2.07	1.10	1.46	1.54	0.25	0.00
Toluene	2.31	0.16	0.31	0.26	0.83	0.06	0.37	0.32	0.00	0.00
Xylenes	3.84	0.16	0.52	1.02	0.84	0.30	0.47	0.53	0.00	0.00
Methanol	0.23	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00
Miscellaneous										
Cracker feed	6.72	0.69	3.68	1.94	0.41	0.00	0.00	0.00	0.00	0.00
Sulphur	3.59	0.15	0.32	0.47	0.78	0.31	0.32	0.73	0.28	0.23
Hydrogen	0.09	0.00	0.00	0.00	0.06	0.00	0.00	0.03	0.00	0.00
Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel & Loss										
Chemical loss	7.49	0.02	1.17	0.20	1.22	0.09	0.15	2.70	1.25	0.69
Refinery fuel										
Gas	25.92	1.52	3.67	3.83	4.76	3.16	2.30	4.16	1.15	1.38
Liquid	12.18	0.87	0.35	0.97	2.48	1.39	1.82	2.21	1.51	0.57
Solid	6.56	0.37	1.31	0.60	0.98	0.97	0.60	0.85	0.31	0.58

Material balance: Both fuels at 50 ppm S
(Core scenario)
All figures in Mt/a

	Total	SCA	UKI	BEN	MEU	FRA	IBE	ITG	EEU	SEU
In										
Crude	760.50	51.36	94.31	97.31	120.89	95.31	83.39	130.05	46.44	41.44
LS	412.50	38.38	73.50	56.42	69.21	60.33	45.81	49.97	18.16	0.71
HS	348.00	12.98	20.81	40.89	51.68	34.98	37.58	80.08	28.28	40.73
Other feeds and components										
Naphthas and mogas comp	12.22	2.11	0.00	1.32	4.42	2.87	0.00	0.00	0.63	0.88
Gasoils	3.65	0.00	0.00	0.00	3.65	0.00	0.00	0.00	0.00	0.00
Cracker feed	4.07	0.00	2.65	1.00	0.42	0.00	0.00	0.00	0.00	0.00
Methanol	1.08	0.07	0.25	0.10	0.00	0.17	0.12	0.18	0.08	0.10
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE	2.10	0.04	0.55	0.00	0.00	0.12	0.32	1.07	0.00	0.00
ETBE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethane	2.50	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nat gas	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.75	0.00	0.00	0.06	0.42	0.03	0.05	0.13	0.05	0.00
Out										
Main products										
LPG	19.56	2.07	2.44	1.72	1.67	3.47	2.74	2.83	1.67	0.95
Gasolines	156.34	9.84	24.06	14.66	26.52	19.39	14.34	26.24	10.60	10.67
Jet	68.77	4.16	13.18	10.23	13.28	9.76	7.87	8.18	1.50	0.59
AGO	194.35	10.99	23.32	22.61	33.23	20.91	27.08	35.17	8.78	12.26
IGO + gasoil comp.	92.76	11.25	7.00	9.75	18.62	14.04	5.67	13.33	10.08	3.03
LSFO	58.79	7.25	8.08	9.89	7.53	7.86	5.21	8.37	4.39	0.22
HSFO	35.14	0.00	1.44	7.98	3.24	2.82	6.41	6.47	0.36	6.42
Bitumen	20.26	0.31	2.15	0.70	4.28	3.74	2.67	2.93	2.77	0.71
Lubs and waxes	9.56	0.31	0.91	1.12	2.03	1.42	1.05	1.06	1.32	0.34
Coke	3.85	0.33	0.59	0.49	1.28	0.00	0.56	0.61	0.00	0.00
Electricity (TWh/a)	24.00	0.00	5.00	0.00	1.50	0.00	0.00	10.00	5.00	2.50
Petrochemicals										
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	26.70	1.43	2.67	5.49	5.65	3.64	1.97	3.54	1.29	1.01
Propylene	17.96	1.04	1.34	3.29	3.69	2.67	1.52	2.55	0.91	0.95
C4 olefins	2.94	0.00	0.21	0.46	0.94	0.48	0.24	0.36	0.15	0.10
Benzene	9.88	0.61	0.88	1.99	2.11	1.10	1.46	1.48	0.25	0.00
Toluene	2.31	0.16	0.31	0.26	0.83	0.06	0.37	0.32	0.00	0.00
Xylenes	3.84	0.16	0.52	1.02	0.84	0.30	0.47	0.53	0.00	0.00
Methanol	0.23	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00
Miscellaneous										
Cracker feed	6.72	0.69	3.68	1.94	0.41	0.00	0.00	0.00	0.00	0.00
Sulphur	3.67	0.15	0.31	0.49	0.78	0.32	0.34	0.76	0.29	0.23
Hydrogen	0.09	0.00	0.00	0.00	0.06	0.00	0.00	0.03	0.00	0.00
Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel & Loss										
Chemical loss	7.73	0.03	1.16	0.25	1.23	0.12	0.19	2.80	1.27	0.69
Refinery fuel										
Gas	26.26	1.51	3.60	3.94	4.80	3.18	2.37	4.36	1.12	1.38
Liquid	12.71	0.92	0.57	1.01	2.51	1.51	1.82	2.19	1.60	0.58
Solid	6.55	0.36	1.29	0.61	1.02	0.97	0.60	0.82	0.30	0.59

Material balance: Both fuels at 10 ppm S
(Core scenario)

All figures in Mt/a

	Total	EU-25	SCA	UKI	BEN	MEU	FRA	IBE	ITG	EEU	SEU
In											
Crude	761.52	720.24	51.48	94.86	97.59	114.69	95.90	83.84	135.38	46.50	41.28
LS	412.50	411.79	37.46	73.67	52.37	68.62	61.50	45.62	51.32	21.22	0.71
HS	349.02	308.45	14.02	21.19	45.23	46.07	34.40	38.22	84.05	25.28	40.57
Other feeds and components											
Naphthas and mogas comp	12.22	11.10	1.99	0.00	1.42	5.22	2.24	0.00	0.00	0.24	1.12
Gasoils	3.65	3.65	0.00	0.00	0.00	3.65	0.00	0.00	0.00	0.00	0.00
Cracker feed	4.07	4.07	0.00	2.65	1.00	0.42	0.00	0.00	0.00	0.00	0.00
Methanol	1.10	0.99	0.07	0.25	0.10	0.00	0.18	0.12	0.19	0.08	0.10
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE	2.10	2.10	0.06	0.61	0.00	0.00	0.11	0.45	0.87	0.00	0.00
ETBE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethane	2.50	2.50	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nat gas	0.10	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.82	0.82	0.01	0.00	0.08	0.43	0.04	0.07	0.15	0.04	0.00
Out											
Main products											
LPG	19.56	18.61	2.07	2.44	1.72	1.67	3.47	2.74	2.83	1.67	0.95
Gasolines	156.33	145.65	9.84	24.07	14.66	26.53	19.39	14.36	26.21	10.60	10.67
Jet	68.77	68.18	4.16	13.19	10.23	13.27	9.77	7.88	8.18	1.50	0.60
AGO	194.19	181.94	10.96	23.33	22.58	33.29	20.92	27.04	35.07	8.75	12.25
IGO + gasoil comp.	92.82	89.78	11.28	6.99	9.78	18.62	14.01	5.67	13.33	10.10	3.04
LSFO	58.79	58.58	7.26	8.09	9.86	7.54	7.86	5.22	8.37	4.39	0.21
HSFO	35.15	28.73	0.00	1.43	8.01	3.23	2.81	6.42	6.47	0.36	6.42
Bitumen	20.26	19.55	0.31	2.15	0.70	4.28	3.74	2.67	2.93	2.77	0.71
Lubs and waxes	9.56	9.22	0.31	0.91	1.12	2.03	1.42	1.05	1.06	1.32	0.34
Coke	3.85	3.85	0.33	0.59	0.49	1.28	0.00	0.56	0.61	0.00	0.00
Electricity (TWh/a)	24.00	21.50	0.00	5.00	0.00	1.50	0.00	0.00	10.00	5.00	2.50
Petrochemicals											
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	26.70	25.69	1.42	2.67	5.53	5.80	3.60	1.97	3.41	1.29	1.01
Propylene	17.96	17.00	1.04	1.33	3.30	3.73	2.68	1.52	2.49	0.91	0.96
C4 olefins	2.94	2.84	0.00	0.21	0.46	0.94	0.48	0.24	0.36	0.15	0.10
Benzene	9.88	9.88	0.54	0.91	1.99	2.25	1.10	1.46	1.38	0.25	0.00
Toluene	2.31	2.31	0.16	0.31	0.26	0.83	0.06	0.37	0.32	0.00	0.00
Xylenes	3.84	3.84	0.16	0.52	1.02	0.84	0.30	0.47	0.53	0.00	0.00
Methanol	0.23	0.23	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00
Miscellaneous											
Cracker feed	6.72	6.72	0.69	3.68	1.94	0.41	0.00	0.00	0.00	0.00	0.00
Sulphur	3.70	3.47	0.16	0.33	0.53	0.74	0.32	0.34	0.77	0.26	0.23
Hydrogen	0.09	0.09	0.00	0.00	0.00	0.06	0.00	0.00	0.03	0.00	0.00
Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel & Loss											
Chemical loss	7.80	7.14	0.04	1.14	0.31	1.25	0.17	0.23	2.76	1.23	0.67
Refinery fuel											
Gas	26.04	24.65	1.46	3.40	3.86	4.90	3.08	2.30	4.51	1.15	1.39
Liquid	14.04	13.45	1.05	0.94	1.31	2.54	1.76	2.04	2.21	1.60	0.58
Solid	6.54	5.93	0.37	1.28	0.61	0.96	0.97	0.60	0.84	0.30	0.61

Material balance: Gasoline at 10 ppm, diesel at 50 ppm S
(Core scenario)

All figures in Mt/a

	Total	SCA	UKI	BEN	MEU	FRA	IBE	ITG	EEU	SEU
In										
Crude	761.26	51.48	94.50	97.31	119.10	97.36	83.65	130.18	46.33	41.33
LS	412.50	37.68	73.72	52.44	69.13	60.31	45.21	52.10	21.19	0.71
HS	348.76	13.80	20.78	44.87	49.97	37.04	38.45	78.09	25.14	40.62
Other feeds and components										
Naphthas and mogas comp	12.22	2.05	0.00	1.59	5.03	2.04	0.00	0.00	0.41	1.10
Gasoils	3.65	0.00	0.00	0.00	3.65	0.00	0.00	0.00	0.00	0.00
Cracker feed	4.07	0.00	2.65	1.00	0.42	0.00	0.00	0.00	0.00	0.00
Methanol	1.10	0.07	0.25	0.10	0.00	0.18	0.12	0.20	0.08	0.10
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE	2.10	0.07	0.64	0.00	0.00	0.11	0.45	0.83	0.00	0.00
ETBE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethane	2.50	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nat gas	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.78	0.01	0.00	0.07	0.43	0.03	0.06	0.14	0.04	0.00
Out										
Main products										
LPG	19.56	2.07	2.44	1.72	1.67	3.47	2.74	2.83	1.67	0.95
Gasolines	156.33	9.85	24.08	14.66	26.53	19.39	14.36	26.20	10.60	10.67
Jet	68.77	4.16	13.18	10.23	13.28	9.76	7.87	8.18	1.50	0.60
AGO	194.34	10.99	23.33	22.61	33.23	20.90	27.08	35.17	8.78	12.26
IGO + gasoil comp.	92.75	11.25	7.00	9.75	18.62	14.03	5.67	13.33	10.07	3.03
LSFO	58.78	7.26	8.09	9.84	7.53	7.86	5.22	8.38	4.39	0.21
HSFO	35.18	0.00	1.44	8.02	3.23	2.81	6.42	6.47	0.36	6.42
Bitumen	20.26	0.31	2.15	0.70	4.28	3.74	2.67	2.93	2.77	0.71
Lubs and waxes	9.56	0.31	0.91	1.12	2.03	1.42	1.05	1.06	1.32	0.34
Coke	3.85	0.33	0.59	0.49	1.28	0.00	0.56	0.61	0.00	0.00
Electricity (TWh/a)	24.00	0.00	5.00	0.00	1.50	0.00	0.00	10.00	5.00	2.50
Petrochemicals										
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	26.70	1.42	2.67	5.53	5.75	3.65	1.97	3.41	1.30	1.00
Propylene	17.96	1.04	1.32	3.31	3.70	2.70	1.52	2.51	0.91	0.95
C4 olefins	2.94	0.00	0.21	0.46	0.94	0.48	0.24	0.36	0.15	0.10
Benzene	9.88	0.62	0.83	1.99	2.24	1.10	1.46	1.39	0.25	0.00
Toluene	2.31	0.16	0.31	0.26	0.83	0.06	0.37	0.32	0.00	0.00
Xylenes	3.84	0.16	0.52	1.02	0.84	0.30	0.47	0.53	0.00	0.00
Methanol	0.23	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00
Miscellaneous										
Cracker feed	6.72	0.69	3.68	1.94	0.41	0.00	0.00	0.00	0.00	0.00
Sulphur	3.69	0.16	0.32	0.53	0.76	0.32	0.35	0.76	0.26	0.23
Hydrogen	0.09	0.00	0.00	0.00	0.06	0.00	0.00	0.03	0.00	0.00
Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel & Loss										
Chemical loss	7.69	0.04	1.14	0.28	1.24	0.13	0.21	2.75	1.23	0.67
Refinery fuel										
Gas	26.29	1.50	3.52	3.89	4.87	3.15	2.33	4.49	1.16	1.38
Liquid	13.51	0.99	0.76	1.22	2.64	1.66	1.96	2.12	1.58	0.59
Solid	6.55	0.36	1.28	0.61	0.96	0.97	0.60	0.86	0.30	0.61

Material balance: Diesel at 10 ppm, gasoline at 50 ppm S
(Core scenario)

All figures in Mt/a

	Total	SCA	UKI	BEN	MEU	FRA	IBE	ITG	EEU	SEU
In										
Crude	760.72	51.39	94.75	97.51	114.42	95.04	84.01	135.44	46.71	41.45
LS	412.50	37.77	73.91	52.34	72.82	61.23	45.77	49.60	18.35	0.71
HS	348.22	13.62	20.84	45.17	41.59	33.81	38.24	85.84	28.36	40.74
Other feeds and components										
Naphthas and mogas comp	12.22	2.04	0.00	1.34	5.02	2.57	0.00	0.00	0.34	0.91
Gasoils	3.65	0.00	0.00	0.00	3.65	0.00	0.00	0.00	0.00	0.00
Cracker feed	4.07	0.00	2.65	1.00	0.42	0.00	0.00	0.00	0.00	0.00
Methanol	1.08	0.07	0.25	0.10	0.00	0.17	0.12	0.18	0.08	0.10
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE	2.10	0.05	0.56	0.00	0.00	0.12	0.33	1.04	0.00	0.00
ETBE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isooctene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethane	2.50	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nat gas	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.80	0.01	0.00	0.08	0.42	0.04	0.06	0.15	0.05	0.00
Out										
Main products										
LPG	19.56	2.07	2.44	1.72	1.67	3.47	2.74	2.83	1.67	0.95
Gasolines	156.35	9.85	24.06	14.67	26.52	19.40	14.34	26.24	10.60	10.67
Jet	68.77	4.16	13.19	10.23	13.27	9.77	7.88	8.18	1.50	0.60
AGO	194.21	10.97	23.33	22.57	33.27	20.92	27.04	35.09	8.76	12.26
IGO + gasoil comp.	92.81	11.28	6.99	9.78	18.62	14.01	5.67	13.34	10.09	3.03
LSFO	58.78	7.25	8.08	9.87	7.53	7.86	5.22	8.37	4.39	0.22
HSFO	35.15	0.00	1.44	8.00	3.23	2.81	6.41	6.47	0.36	6.42
Bitumen	20.26	0.31	2.15	0.70	4.28	3.74	2.67	2.93	2.77	0.71
Lubs and waxes	9.56	0.31	0.91	1.12	2.03	1.42	1.05	1.06	1.32	0.34
Coke	3.85	0.33	0.59	0.49	1.28	0.00	0.56	0.61	0.00	0.00
Electricity (TWh/a)	24.00	0.00	5.00	0.00	1.50	0.00	0.00	10.00	5.00	2.50
Petrochemicals										
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	26.70	1.42	2.67	5.51	5.54	3.63	1.97	3.66	1.28	1.02
Propylene	17.96	1.04	1.34	3.29	3.62	2.67	1.52	2.62	0.91	0.95
C4 olefins	2.94	0.00	0.21	0.46	0.94	0.48	0.24	0.36	0.15	0.10
Benzene	9.88	0.55	0.97	1.99	2.06	1.10	1.46	1.49	0.25	0.00
Toluene	2.31	0.16	0.31	0.26	0.83	0.06	0.37	0.32	0.00	0.00
Xylenes	3.84	0.16	0.52	1.02	0.84	0.30	0.47	0.53	0.00	0.00
Methanol	0.23	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00
Miscellaneous										
Cracker feed	6.72	0.69	3.68	1.94	0.41	0.00	0.00	0.00	0.00	0.00
Sulphur	3.68	0.16	0.32	0.53	0.71	0.32	0.34	0.78	0.29	0.23
Hydrogen	0.09	0.00	0.00	0.00	0.06	0.00	0.00	0.03	0.00	0.00
Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel & Loss										
Chemical loss	7.74	0.04	1.14	0.29	1.20	0.16	0.22	2.75	1.27	0.68
Refinery fuel										
Gas	25.86	1.48	3.39	3.88	4.77	3.13	2.31	4.42	1.10	1.39
Liquid	13.45	0.98	0.85	1.21	2.44	1.61	1.97	2.20	1.63	0.57
Solid	6.52	0.36	1.29	0.61	0.98	0.97	0.60	0.82	0.30	0.59

APPENDIX 3: NEW UNIT CAPACITY AND INVESTMENT

Total for EU-25 + Norway & Switzerland

		Capacity Mt/a					Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
EU-25+2											
CDU	743.07	9.97	8.51	10.38	11.02	9.50	72	59	72	76	67
HVU	298.92	1.55	1.98	2.10	2.67	2.47	17	20	21	27	25
Visbreaker	78.02										
Del coker	25.92										
C4 deasphalting											
FCC	118.51	0.82	1.40	0.50	0.44	0.78	69	124	46	40	65
Cracked gasoline splitter	7.38	10.48	18.07	32.18	32.43	17.02	100	178	308	310	168
HCU recycle	6.29										
HCU once-through	35.81	0.78	1.51	2.12	1.68	2.65	78	210	280	212	374
Cat feed HT	35.36	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0
LR HDS	5.30										
Resid hydroconversion	2.86										
Naph HT	139.99										
Cracked gasoline HT	1.99	1.18	10.19	24.90	25.49	9.49	92	769	1812	1853	717
Cracked gasoline sweetening		2.09	2.18	3.89	4.30	2.23	126	132	236	259	133
Cat reforming revamp							275	432	689	680	418
Cat reforming (LP)	31.90		1.13	2.69	2.56	1.24		149	351	333	168
Reformate splitter	42.84	3.02	2.98	2.31	2.41	3.48	70	63	46	48	80
Light reformate splitter	8.17	0.95	1.11	1.32	1.32	1.13	28	33	39	38	33
Aromatics Extraction	5.55	1.65	1.61	1.52	1.62	1.52	115	110	105	111	104
Alkylation	8.39	0.03	0.02	0.08	0.08		7	5	29	29	
Isomerisation once-through	1.47	0.64	0.57	0.60	0.62	0.52	98	87	92	95	80
Isomerisation recycle	17.37			0.47	0.49				97	102	
MTBE	2.55	0.43	0.55	0.53	0.54	0.53	201	254	247	249	249
TAME	0.44	2.18	2.10	2.38	2.38	2.28	341	329	370	371	356
Butamer	2.16										
PP splitter	3.94	0.56	0.54	0.55	0.55	0.54	102	99	99	100	98
Kero HT		25.66	27.39	30.15	26.92	30.34	1135	1211	1314	1189	1322
GO HT LP	32.30										
GO HT MP revamp							510	762	828	771	828
GO HT HP	3.80	15.44	30.76	53.14	31.42	52.30	1203	2373	4060	2425	3999
GO HDA											
SRU (as sulphur)	3.49	0.46	0.51	0.47	0.46	0.46	237	280	260	254	259
FGDS	1.09	1.91	1.82	1.99	1.99	1.92	402	383	418	418	404
Bitumen	25.95	0.47	0.47	0.47	0.47	0.47	18	18	18	18	18
Lubs	7.84										
Hydrogen manuf (as hydrogen) [1]	*212*	*196*	*236*	*286*	*252*	*269*	347	416	501	443	472
Hydrogen scavenging [1]	*52*	*206*	*213*	*240*	*222*	*219*	277	287	323	299	295
POX + GT											
IGCC	2.01	3.28	3.32	3.18	3.19	3.19	2545	2579	2474	2485	2480
POX + hydrogen	0.12										
POX + methanol	0.39										
Steam cracker	63.34	12.95	12.79	12.79	12.82	12.74	2607	2578	2569	2586	2578
hydrodealkylation	1.07										
Total							**11071**	**13942**	**17705**	**15822**	**15792**

[1] Capacities expressed in kt/a

Scandinavia

		Capacity Mt/a					Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
SCA: Scandinavia											
CDU	53.78										
HVU	18.65										
Visbreaker	7.66										
Del coker	7.66										
C4 deasphalting											
FCC	6.77	0.39	0.26	0.50	0.44	0.33	35	22	46	40	29
Cracked gasoline splitter	0.73		0.44	1.67	1.65	0.45		5	16	16	5
HCU recycle											
HCU once-through	3.39										
Cat feed HT	2.35										
LR HDS											
Resid hydroconversion											
Naph HT	10.38										
Cracked gasoline HT			0.22	1.71	1.70	0.23		17	125	124	18
Cracked gasoline sweetening				0.02	0.03				2	2	
Cat reforming revamp									3	3	
Cat reforming (LP)	3.91										
Reformate splitter	2.30	0.08	0.30	0.30	0.20		1	5	4	3	
Light reformate splitter	0.33	0.26	0.26	0.26	0.23	0.26	7	7	7	6	7
Aromatics Extraction		0.40	0.43	0.34	0.44	0.36	30	32	26	33	27
Alkylation	0.47										
Isomerisation once-through											
Isomerisation recycle	1.92										
MTBE	0.17	0.03	0.02	0.03	0.02	0.02	13	11	13	13	12
TAME											
Butamer											
PP splitter	0.21	0.08	0.07	0.08	0.07	0.07	13	12	13	13	13
Kero HT		0.67	1.12	3.52	1.21	3.45	31	51	155	55	152
GO HT LP	5.28										
GO HT MP revamp							15	15	15	15	15
GO HT HP		1.67	2.95	3.78	2.92	3.90	133	231	293	228	302
GO HDA											
SRU	0.16		0.00	0.01	0.01	0.01		0	2	2	1
FGDS		0.16	0.16	0.16	0.16	0.16	33	33	33	33	33
Bitumen	2.84										
Lubs	0.13										
Hydrogen manuf (as hydrogen) (1)			*3*	*8*	*6*	*5*		5	13	10	9
Hydrogen scavenging (1)	*8*	*15*	*16*	*16*	*16*	*16*	20	22	21	22	21
POX + GT											
IGCC											
POX + hydrogen											
POX + methanol											
Steam cracker	4.21										
hydrodealkylation	0.07										
Total							**331**	**469**	**790**	**619**	**646**

(1) Capacities expressed in kt/a

UK & Ireland

	Capacity Mt/a						Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
UKI: UK & Ireland											
CDU	91.16	4.14	3.15	3.70	3.34	3.59	29	21	25	23	24
HVU	43.37										
Visbreaker	3.19										
Del coker	3.97										
C4 deasphalting											
FCC	24.08										
Cracked gasoline splitter	0.80		2.49	4.65	4.66	2.41		25	45	45	24
HCU recycle											
HCU once-through	2.10										
Cat feed HT	1.92										
LR HDS	1.24										
Resid hydroconversion											
Naph HT	19.32										
Cracked gasoline HT	0.08		3.06	5.83	5.78	2.82		225	411	408	209
Cracked gasoline sweetening											
Cat reforming revamp									23	23	
Cat reforming (LP)	4.47			0.52	0.50				55	51	
Reformate splitter	8.37										
Light reformate splitter	2.39										
Aromatics Extraction	0.96	0.13	0.14	0.12	0.15	0.12	7	8	6	8	6
Alkylation	1.97										
Isomerisation once-through											
Isomerisation recycle	2.85										
MTBE	0.25	0.33	0.44	0.44	0.43	0.44	165	216	214	213	216
TAME											
Butamer	1.89										
PP splitter	0.83	0.17	0.10	0.09	0.08	0.10	29	15	13	11	15
Kero HT			0.69		0.15	0.30		32		7	14
GO HT LP	1.31										
GO HT MP revamp							22	132	198	141	198
GO HT HP	2.96			3.52		3.17			307		281
GO HDA											
SRU	0.35			0.01					3		
FGDS		0.26	0.20	0.28	0.27	0.26	54	42	58	56	54
Bitumen	3.05										
Lubs	1.06										
Hydrogen manuf (as hydrogen) [(1)]											
Hydrogen scavenging [(1)]				*16*		*4*			22		6
POX + GT											
IGCC		1.19	1.17	1.17	1.15	1.16	928	917	916	898	910
POX + hydrogen											
POX + methanol											
Steam cracker	3.96	0.64	0.68	0.73	0.70	0.69	118	128	140	134	131
hydrodealkylation	0.07										
Total							**1352**	**1762**	**2436**	**2019**	**2088**

[(1)] Capacities expressed in kt/a

Benelux

		Capacity Mt/a					Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
BEN: Benelux											
CDU	97.31			0.28		0.19			2		1
HVU	38.64										
Visbreaker	8.87										
Del coker	2.14										
C4 deasphalting											
FCC	11.79										
Cracked gasoline splitter	2.06			0.84	0.98				9	10	
HCU recycle	2.63										
HCU once-through	4.65										
Cat feed HT	5.36										
LR HDS	4.06										
Resid hydroconversion	1.47										
Naph HT	17.74										
Cracked gasoline HT	0.08	0.15	0.34	2.32	2.36	0.28	12	27	166	169	22
Cracked gasoline sweetening				0.29	0.30				19	19	
Cat reforming revamp							15	19	26	30	17
Cat reforming (LP)	7.33										
Reformate splitter	3.77										
Light reformate splitter	0.75										
Aromatics Extraction	1.26	0.38	0.32	0.32	0.32	0.33	26	20	21	21	21
Alkylation	0.72										
Isomerisation once-through											
Isomerisation recycle	0.34										
MTBE	0.26		0.02	0.02	0.02	0.02		7	6	6	7
TAME											
Butamer											
PP splitter	0.37	0.03	0.05	0.04	0.04	0.05	6	10	9	9	10
Kero HT		2.91	3.07	4.19	3.51	4.33	129	136	181	154	187
GO HT LP	7.41										
GO HT MP revamp							27	104	104	104	104
GO HT HP			1.27	4.82	1.51	4.79		101	366	120	364
GO HDA											
SRU	0.86										
FGDS											
Bitumen	2.20										
Lubs	0.61										
Hydrogen manuf (as hydrogen) [(1)]	*119*										
Hydrogen scavenging [(1)]	*2*	*38*	*37*	*38*	*38*	*37*	50	49	49	49	49
POX + GT											
IGCC											
POX + hydrogen											
POX + methanol											
Steam cracker	14.80	1.51	2.28	2.40	2.41	2.34	242	414	443	445	429
hydrodealkylation	0.25										
Total							**507**	**886**	**1400**	**1136**	**1212**

[(1)] Capacities expressed in kt/a

Mid-Europe

		Capacity Mt/a					Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
MEU: Mid-Europe											
CDU	130.57										
HVU	52.89		0.52	0.82	1.29	0.90		5	8	13	9
Visbreaker	14.61										
Del coker	7.10										
C4 deasphalting											
FCC	19.60	0.43	1.14			0.44	34	102			36
Cracked gasoline splitter	0.84	7.39	6.11	8.99	9.00	5.54	69	58	83	83	53
HCU recycle											
HCU once-through	8.39	0.40	0.18	1.31	1.45	0.80	38	16	166	190	88
Cat feed HT	12.60										
LR HDS											
Resid hydroconversion											
Naph HT	26.69										
Cracked gasoline HT			1.58	3.58	3.78	1.33		122	263	277	103
Cracked gasoline sweetening		1.51	1.34	1.64	1.75	1.51	90	81	98	104	90
Cat reforming revamp							211	300	382	367	276
Cat reforming (LP)	8.38										
Reformate splitter	5.48	1.27	0.87			1.73	34	21			44
Light reformate splitter	0.96	0.48	0.50	0.66	0.66	0.53	15	16	20	20	17
Aromatics Extraction	1.70										
Alkylation	1.22										
Isomerisation once-through	0.14										
Isomerisation recycle	4.03										
MTBE	0.47	0.02	0.04	0.01	0.01	0.02	7	14	3	3	7
TAME		1.57	1.40	1.68	1.68	1.57	245	220	261	262	245
Butamer											
PP splitter	0.69	0.03	0.06	0.02	0.02	0.03	7	13	3	3	7
Kero HT		5.33	4.44	1.73	4.20	1.18	236	198	79	188	54
GO HT LP	3.15										
GO HT MP revamp							137	137	137	137	137
GO HT HP	0.83	4.30	8.45	11.98	8.24	11.98	338	646	893	631	893
GO HDA											
SRU	0.60	0.19	0.20	0.15	0.18	0.12	109	112	93	104	81
FGDS	1.01										
Bitumen	5.95										
Lubs	1.18										
Hydrogen manuf (as hydrogen) [(1)]	*25*	*83*	*86*	*92*	*90*	*81*	146	151	162	158	143
Hydrogen scavenging [(1)]	*7*	*49*	*54*	*59*	*59*	*55*	66	72	79	78	73
POX + GT											
IGCC	0.54										
POX + hydrogen	0.08										
POX + methanol	0.39										
Steam cracker	15.89	1.65	1.50	2.00	1.81	1.19	267	238	341	301	178
hydrodealkylation	0.27										
Total							**2050**	**2521**	**3070**	**2919**	**2534**

[(1)] Capacities expressed in kt/a

France

	Capacity Mt/a						Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
FRA: France											
CDU	94.59		0.72	1.30	2.76	0.44		4	8	18	3
HVU	41.62										
Visbreaker	9.10										
Del coker											
C4 deasphalting											
FCC	19.02										
Cracked gasoline splitter	1.90		1.29	4.39	4.28	1.01		14	43	43	11
HCU recycle											
HCU once-through	0.94		0.48	0.49		0.84		81	82		143
Cat feed HT	5.60										
LR HDS											
Resid hydroconversion											
Naph HT	20.04										
Cracked gasoline HT	0.19	0.58	1.34	4.09	4.02	1.28	46	104	305	300	100
Cracked gasoline sweetening			0.04	0.18	0.12			3	12	8	
Cat reforming revamp							42	94	131	133	108
Cat reforming (LP)											
Reformate splitter	6.61										
Light reformate splitter	1.10										
Aromatics Extraction	0.02	0.17	0.12	0.09	0.08	0.10	14	10	8	6	8
Alkylation	1.25										
Isomerisation once-through											
Isomerisation recycle	3.30										
MTBE	0.47										
TAME	0.12										
Butamer	0.18										
PP splitter	0.64	0.07	0.08	0.12	0.12	0.09	14	17	26	25	19
Kero HT		2.72	2.41	2.44	2.54	2.38	122	109	110	115	108
GO HT LP	2.95										
GO HT MP revamp							114	144	144	144	144
GO HT HP			1.46	4.90	1.94	4.68		116	378	154	362
GO HDA											
SRU	0.28	0.04	0.05	0.05	0.05	0.05	14	21	23	23	23
FGDS		0.52	0.52	0.52	0.53	0.52	109	109	109	111	109
Bitumen	3.42	0.36	0.36	0.36	0.36	0.36	15	15	15	15	15
Lubs	1.76										
Hydrogen manuf (as hydrogen) [(1)]		*17*	*25*	*41*	*29*	*38*	30	43	72	51	66
Hydrogen scavenging [(1)]	*5*	*28*	*28*	*29*	*29*	*28*	38	38	39	39	38
POX + GT											
IGCC											
POX + hydrogen											
POX + methanol											
Steam cracker	9.55	2.09	2.11	1.97	2.15	2.09	431	437	400	449	432
hydrodealkylation	0.16										
Total							**986**	**1360**	**1904**	**1632**	**1688**

[(1)] Capacities expressed in kt/a

Iberia

	Capacity Mt/a						Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
IBE: Iberia											
CDU	78.74	5.83	4.65	5.09	4.91	5.27	44	33	37	36	39
HVU	27.84	1.55	1.47	1.28	1.38	1.58	17	16	13	14	17
Visbreaker	9.91										
Del coker	2.42										
C4 deasphalting											
FCC	11.66										
Cracked gasoline splitter		1.14	2.58	4.02	4.05	2.58	12	26	39	39	26
HCU recycle	2.27										
HCU once-through	2.30										
Cat feed HT	3.74										
LR HDS											
Resid hydroconversion											
Naph HT	15.55										
Cracked gasoline HT	0.10	0.01	1.01	3.24	3.27	1.01	1	78	236	238	78
Cracked gasoline sweetening				0.08	0.10				5	6	
Cat reforming revamp									2	2	
Cat reforming (LP)	1.48										
Reformate splitter	4.82										
Light reformate splitter	0.86		0.06	0.09	0.10	0.04		2	3	3	2
Aromatics Extraction	0.97	0.53	0.50	0.51	0.51	0.51	37	35	36	36	36
Alkylation	0.85	0.00					0				
Isomerisation once-through	0.21										
Isomerisation recycle	0.59										
MTBE	0.31	0.01	0.01	0.01	0.01	0.01	2	3	3	3	3
TAME											
Butamer											
PP splitter	0.44	0.02	0.04	0.04	0.04	0.04	5	8	8	8	8
Kero HT		3.40	3.78	5.78	3.89	5.81	151	167	248	171	249
GO HT LP	3.68										
GO HT MP revamp							88	122	122	122	122
GO HT HP			2.68	5.94	2.87	6.06		211	452	225	460
GO HDA											
SRU	0.38										
FGDS		0.17	0.16	0.24	0.22	0.20	35	34	51	46	42
Bitumen	2.67	0.03	0.03	0.03	0.03	0.03	1	1	1	1	1
Lubs	0.62										
Hydrogen manuf (as hydrogen) (1)	*26*	*10*	*18*	*32*	*24*	*28*	19	33	57	44	51
Hydrogen scavenging (1)	*4*	*30*	*31*	*31*	*31*	*31*	40	41	42	42	41
POX + GT											
IGCC											
POX + hydrogen											
POX + methanol											
Steam cracker	5.04	1.10	1.02	0.98	0.99	1.02	227	205	195	196	206
hydrodealkylation	0.09										
Total							**678**	**1015**	**1547**	**1231**	**1378**

(1) Capacities expressed in kt/a

Italy & Greece

		Capacity Mt/a					Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
ITG: Italy & Greece											
CDU	138.19										
HVU	50.18										
Visbreaker	22.05										
Del coker	2.63										
C4 deasphalting											
FCC	19.62										
Cracked gasoline splitter	0.46	0.02	2.66	4.78	4.99	2.59	0	27	46	48	26
HCU recycle	1.40										
HCU once-through	9.24										
Cat feed HT	1.90										
LR HDS											
Resid hydroconversion	1.39										
Naph HT	22.62										
Cracked gasoline HT	1.52		1.08	2.83	3.29	0.97		80	209	241	72
Cracked gasoline sweetening			0.12	0.73	1.05	0.03		8	46	65	2
Cat reforming revamp									0	1	1
Cat reforming (LP)	4.72		1.13	1.86	1.73	1.24		149	259	241	168
Reformate splitter	8.39										
Light reformate splitter	1.78										
Aromatics Extraction	0.65	0.04	0.09	0.14	0.12	0.10	2	5	8	7	5
Alkylation	1.58										
Isomerisation once-through	1.02										
Isomerisation recycle	3.13										
MTBE	0.47	0.02	0.00	0.02	0.03	0.01	7	1	6	10	3
TAME	0.32										
Butamer	0.09										
PP splitter	0.55	0.15	0.14	0.15	0.17	0.15	25	24	26	30	26
Kero HT		8.65	9.20	10.13	9.06	10.21	376	398	435	392	438
GO HT LP	5.41										
GO HT MP revamp							107	107	107	107	107
GO HT HP		4.25	8.65	12.84	8.73	12.28	335	665	964	671	925
GO HDA											
SRU	0.69	0.09	0.13	0.13	0.12	0.14	55	85	90	77	93
FGDS	0.08	0.81	0.78	0.79	0.81	0.78	170	165	167	171	166
Bitumen	2.88	0.08	0.08	0.08	0.08	0.08	3	3	3	3	3
Lubs	1.62										
Hydrogen manuf (as hydrogen) (1)	*19*	*67*	*79*	*92*	*83*	*89*	117	138	160	145	155
Hydrogen scavenging (1)	*19*	*34*	*35*	*37*	*35*	*36*	47	48	51	49	49
POX + GT											
IGCC	1.47	0.93	1.00	0.88	0.91	0.88	709	758	668	696	668
POX + hydrogen	0.04										
POX + methanol											
Steam cracker	6.47	5.38	4.66	4.14	4.17	4.89	1212	1059	945	951	1108
hydrodealkylation	0.11										
Total							**3166**	**3721**	**4190**	**3904**	**4014**

(1) Capacities expressed in kt/a

Eastern Europe

		Capacity Mt/a					Capex M€				
Sulphur specification (ppm)		Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm	Reference	Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10 ppm	Diesel 10 ppm
Gasoline		*150*	*50*	*10*	*10*	*50*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*50*	*10*	*50*	*10*	*350*	*50*	*10*	*50*	*10*
	Existing	New									
EEU: Eastern Europe											
CDU	58.72										
HVU	25.73										
Visbreaker	2.64										
Del coker											
C4 deasphalting											
FCC	5.97										
Cracked gasoline splitter	0.59	1.92	2.50	2.84	2.82	2.45	19	24	27	27	23
HCU recycle											
HCU once-through	4.81	0.38	0.86	0.32	0.22	1.01	40	114	33	22	142
Cat feed HT	1.90	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0
LR HDS											
Resid hydroconversion											
Naph HT	7.66										
Cracked gasoline HT		0.44	1.56	1.30	1.29	1.58	34	115	97	97	116
Cracked gasoline sweetening		0.59	0.67	0.94	0.94	0.69	35	40	55	55	41
Cat reforming revamp							7	18	121	121	16
Cat reforming (LP)	1.62			0.31	0.32				38	40	
Reformate splitter	3.10	1.67	1.81	2.02	2.21	1.75	35	38	42	46	37
Light reformate splitter		0.21	0.29	0.31	0.33	0.30	6	8	8	9	8
Aromatics Extraction											
Alkylation	0.33	0.03	0.02	0.08	0.08		7	5	29	29	
Isomerisation once-through	0.10	0.64	0.57	0.60	0.62	0.52	98	87	92	95	80
Isomerisation recycle	1.19			0.47	0.49				97	102	
MTBE	0.15	0.02	0.01	0.01	0.01	0.01	6	2	2	2	2
TAME		0.61	0.70	0.70	0.70	0.71	96	109	109	109	111
Butamer											
PP splitter	0.22	0.01	0.01	0.01	0.01	0.01	1	1	2	1	2
Kero HT		1.99	2.68	2.36	2.37	2.69	90	120	106	106	120
GO HT LP	3.12										
GO HT MP revamp											
GO HT HP		5.22	5.30	5.36	5.21	5.43	397	403	407	397	412
GO HDA											
SRU	0.17	0.14	0.14	0.12	0.11	0.14	58	60	49	49	61
FGDS											
Bitumen	2.94										
Lubs	0.87										
Hydrogen manuf (as hydrogen) (1)	*23*	*19*	*25*	*21*	*19*	*27*	35	45	37	35	48
Hydrogen scavenging (1)	*8*	*12*	*13*	*15*	*15*	*13*	16	18	20	20	17
POX + GT											
IGCC		1.16	1.15	1.13	1.13	1.15	908	904	890	891	902
POX + hydrogen											
POX + methanol											
Steam cracker	3.43	0.58	0.53	0.57	0.59	0.51	110	96	106	111	93
hydrodealkylation	0.06										
Total							**1999**	**2208**	**2368**	**2363**	**2232**

(1) Capacities expressed in kt/a

APPENDIX 4: ROAD FUELS QUALITY

(Total and per region for each case)

GASOLINE

		Gasoline 150 ppm Diesel 350 ppm		Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Year		2000	2010				
Sulphur specification (ppm)		Base	Reference				
Gasoline		*150*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*350*	*50*	*10*	*50*	*10*
Total							
Production	*Mt/a*	*120.6*	*123.0*	*123.3*	*123.2*	*123.2*	*123.3*
Density		0.750	0.747	0.747	0.745	0.745	0.748
		1.334	1.339	1.338	1.342	1.342	1.337
Sulphur	ppm	140	124	40	7	7	40
Olefins	% v/v	14.3	14.7	13.6	10.2	10.3	13.6
Aromatics	% v/v	35.5	32.7	32.9	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.6	0.7	0.8	0.7	0.7	0.8
RON		95.5	95.4	95.3	95.3	95.3	95.3
MON		85.4	85.3	85.4	85.5	85.5	85.4
LHV	GJ/t	43.1	43.1	43.0	43.1	43.1	43.0
SCA							
Production	*Mt/a*	*9.4*	*8.9*	*8.9*	*8.9*	*8.9*	*8.9*
Density		0.749	0.745	0.746	0.744	0.744	0.745
		1.335	1.342	1.341	1.343	1.343	1.343
Sulphur	ppm	140	58	40	7	7	40
Olefins	% v/v	13.3	14.0	13.5	11.3	11.3	13.6
Aromatics	% v/v	36.2	33.0	33.0	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.4	0.4	0.5	0.5	0.5	0.5
RON		95.3	95.3	95.3	95.3	95.3	95.3
MON		85.3	85.3	85.3	85.4	85.4	85.3
LHV	GJ/t	43.1	43.2	43.2	43.1	43.1	43.1
UKI							
Production	*Mt/a*	*22.5*	*22.0*	*22.1*	*22.1*	*22.1*	*22.1*
Density		0.744	0.747	0.747	0.744	0.744	0.748
		1.344	1.339	1.338	1.344	1.344	1.337
Sulphur	ppm	140	140	40	7	7	40
Olefins	% v/v	13.7	12.1	11.0	7.4	7.4	11.0
Aromatics	% v/v	33.6	33.0	33.0	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.7	0.9	1.0	1.0	1.0	1.0
RON		95.3	95.3	95.3	95.3	95.3	95.3
MON		85.3	85.3	85.3	85.4	85.4	85.3
LHV	GJ/t	43.1	43.0	42.9	42.9	42.9	42.9
BEN							
Production	*Mt/a*	*11.1*	*10.9*	*11.0*	*10.9*	*10.9*	*11.0*
Density		0.759	0.751	0.751	0.750	0.750	0.751
		1.318	1.331	1.331	1.333	1.333	1.332
Sulphur	ppm	140	70	40	7	7	40
Olefins	% v/v	17.0	17.0	17.0	13.4	13.5	17.0
Aromatics	% v/v	40.0	33.0	33.0	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.4	0.4	0.5	0.4	0.4	0.5
RON		96.3	95.3	95.3	95.3	95.3	95.3
MON		85.3	85.3	85.3	85.3	85.3	85.3
LHV	GJ/t	43.0	43.3	43.2	43.3	43.3	43.2

		Gasoline 150 ppm Diesel 350 ppm		Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Year		2000	2010				
Sulphur specification (ppm)		Base	Reference				
Gasoline		*150*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*350*	*50*	*10*	*50*	*10*
MEU							
Production	*Mt/a*	*27.1*	*26.5*	*26.5*	*26.5*	*26.5*	*26.5*
Density		0.744	0.746	0.746	0.744	0.744	0.747
		1.343	1.341	1.341	1.344	1.344	1.338
Sulphur	ppm	140	136	40	7	7	40
Olefins	% v/v	14.2	15.4	14.2	10.6	10.7	14.4
Aromatics	% v/v	33.2	31.7	32.5	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.4	0.4	0.4	0.4	0.4	0.4
RON		94.4	95.0	95.0	95.0	95.0	95.0
MON		84.8	85.0	85.0	85.0	85.0	85.3
LHV	GJ/t	43.3	43.3	43.2	43.2	43.2	43.2
FRA							
Production	*Mt/a*	*17.9*	*14.1*	*14.2*	*14.1*	*14.1*	*14.2*
Density		0.750	0.749	0.749	0.744	0.744	0.749
Sulphur	ppm	140	140	40	7	7	40
Olefins	% v/v	15.8	17.0	16.9	12.1	12.0	16.8
Aromatics	% v/v	33.1	33.0	33.0	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.8	0.8	0.8	0.7	0.7	0.8
RON		96.4	96.5	96.1	96.0	96.0	96.1
MON		86.2	86.1	86.1	86.0	86.0	86.1
LHV	GJ/t	43.0	43.1	43.0	43.0	43.0	43.0
IBE							
Production	*Mt/a*	*11.0*	*10.5*	*10.5*	*10.6*	*10.6*	*10.5*
Density		0.760	0.748	0.750	0.747	0.747	0.750
Sulphur	ppm	140	101	40	7	7	40
Olefins	% v/v	16.6	17.0	16.4	12.3	12.2	16.4
Aromatics	% v/v	40.0	33.0	33.0	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.7	0.6	0.6	1.0	1.0	0.6
RON		96.7	95.7	95.8	95.7	95.7	95.8
MON		86.0	85.7	85.8	85.7	85.7	85.8
LHV	GJ/t	42.9	43.1	43.1	43.0	43.0	43.1
ITG							
Production	*Mt/a*	*21.5*	*19.4*	*19.5*	*19.5*	*19.4*	*19.5*
Density		0.752	0.746	0.747	0.745	0.745	0.747
Sulphur	ppm	140	140	40	7	7	40
Olefins	% v/v	12.0	13.0	10.4	7.8	8.3	10.4
Aromatics	% v/v	37.8	33.0	33.0	33.0	33.0	33.0
Benzene	% v/v	0.9	0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v	0.9	1.2	1.4	1.2	1.0	1.4
RON		95.3	95.2	95.2	95.2	95.2	95.2
MON		85.3	85.2	85.2	85.4	85.4	85.2
LHV	GJ/t	42.9	42.9	42.7	42.8	42.9	42.7
EEU							
Production	*Mt/a*		*10.6*	*10.6*	*10.6*	*10.6*	*10.6*
Density			0.747	0.747	0.743	0.743	0.747
Sulphur	ppm		140	40	7	7	40
Olefins	% v/v		14.2	12.7	10.3	10.3	12.9
Aromatics	% v/v		33.0	33.0	33.0	33.0	33.0
Benzene	% v/v		0.9	0.9	0.9	0.9	0.9
Oxygen	% v/v		0.4	0.4	0.4	0.4	0.4
RON			95.3	95.3	95.3	95.3	95.3
MON			85.3	85.4	86.0	86.1	85.3
LHV	GJ/t		43.2	43.2	43.3	43.3	43.2

DIESEL

			Gasoline 150 ppm Diesel 350 ppm		Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Year			2000	2010				
Sulphur specification (ppm)			Base	Reference				
Gasoline			*150*	*150*	*50*	*10*	*10*	*50*
Diesel			*350*	*350*	*50*	*10*	*50*	*10*
Total								
Production		*Mt/a*	*128.2*	*182.9*	*182.6*	*182.5*	*182.6*	*182.5*
	Density		0.831	0.840	0.837	0.831	0.836	0.832
	Sulphur	ppm	340	340	40	7	40	7
	Viscosity	V50	8.4	10.0	9.7	9.3	9.7	9.4
	Aromatics	% m/m	29.6	31.5	30.4	28.7	30.5	28.7
	Cloud pt	°C	-10.6	-7.1	-6.5	-8.3	-6.7	-8.2
	E350	% v/v	95.0	91.7	91.4	92.0	91.5	91.9
	CN Ind		49.0	49.1	49.7	50.3	49.6	50.3
	Polyarom	% m/m	5.6	6.4	5.5	4.2	5.4	4.2
	LHV	GJ/t	43.4	43.3	43.4	43.4	43.4	43.4
SCA								
Production		*Mt/a*	*7.3*	*11.0*	*11.0*	*11.0*	*11.0*	*11.0*
	Density		0.832	0.840	0.834	0.822	0.834	0.822
	Sulphur	ppm	340	340	40	7	40	7
	Viscosity	V50	8.4	10.1	9.5	7.6	9.5	7.7
	Aromatics	% m/m	28.6	30.2	30.4	25.5	30.2	25.4
	Cloud pt	°C	-10.0	-8.1	-9.1	-11.4	-9.0	-11.5
	E350	% v/v	95.0	91.5	92.6	93.9	92.5	94.0
	CN Ind		49.0	49.0	49.0	49.0	49.1	49.0
	Polyarom	% m/m	5.6	6.2	5.4	3.2	5.5	3.2
	LHV	GJ/t	43.5	43.3	43.4	43.5	43.4	43.5
UKI								
Production		*Mt/a*	*16.8*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
	Density		0.840	0.840	0.840	0.838	0.840	0.838
	Sulphur	ppm	340	340	40	7	40	7
	Viscosity	V50	9.5	10.6	11.1	11.3	11.1	11.4
	Aromatics	% m/m	32.4	31.7	31.0	30.3	31.8	30.0
	Cloud pt	°C	-9.7	-5.9	-5.0	-5.2	-5.0	-5.0
	E350	% v/v	95.0	92.5	91.3	91.3	91.4	91.2
	CN Ind		49.0	50.1	51.4	52.1	50.9	52.2
	Polyarom	% m/m	6.2	6.8	6.1	4.7	6.0	4.8
	LHV	GJ/t	43.3	43.3	43.4	43.4	43.4	43.4
BEN								
Production		*Mt/a*	*21.7*	*22.7*	*22.6*	*22.6*	*22.6*	*22.6*
	Density		0.832	0.840	0.834	0.825	0.833	0.825
	Sulphur	ppm	340	340	40	7	40	7
	Viscosity	V50	8.4	9.9	9.9	9.2	9.6	9.2
	Aromatics	% m/m	30.9	31.5	28.5	26.0	28.6	25.9
	Cloud pt	°C	-9.7	-6.5	-5.0	-6.5	-5.4	-6.5
	E350	% v/v	95.0	92.0	91.0	91.2	91.1	91.2
	CN Ind		49.3	49.0	51.4	52.0	50.9	51.9
	Polyarom	% m/m	6.2	6.9	5.5	3.7	5.4	3.7
	LHV	GJ/t	43.4	43.3	43.5	43.6	43.5	43.6

See note on cetane index in ***Section 4.5***

		Gasoline 150 ppm Diesel 350 ppm		Both fuels 50 ppm	Both fuels 10 ppm	Gasoline 10ppm	Diesel 10 ppm
Year		2000	2010				
Sulphur specification (ppm)		Base	Reference				
Gasoline		*150*	*150*	*50*	*10*	*10*	*50*
Diesel		*350*	*350*	*50*	*10*	*50*	*10*
MEU							
Production	*Mt/a*	*17.3*	*33.3*	*33.2*	*33.3*	*33.2*	*33.3*
Density		0.840	0.840	0.840	0.840	0.840	0.840
Sulphur	ppm	340	340	40	7	40	7
Viscosity	V50	9.6	9.7	10.0	10.2	10.0	10.3
Aromatics	% m/m	31.5	31.0	31.5	30.6	31.4	30.7
Cloud pt	°C	-9.0	-5.3	-5.3	-5.6	-5.3	-5.4
E350	% v/v	95.0	91.6	90.6	90.8	90.7	90.8
CN Ind		49.0	49.0	49.4	49.6	49.3	49.9
Polyarom	% m/m	6.6	6.1	5.9	4.8	5.9	4.9
LHV	GJ/t	43.4	43.3	43.4	43.3	43.3	43.3
FRA							
Production	*Mt/a*	*15.6*	*20.9*	*20.9*	*20.9*	*20.9*	*20.9*
Density		0.833	0.840	0.840	0.837	0.840	0.838
Sulphur	ppm	340	340	40	7	40	7
Viscosity	V50	8.8	10.1	10.1	9.7	10.1	9.7
Aromatics	% m/m	31.6	32.5	32.5	32.4	32.5	32.2
Cloud pt	°C	-11.8	-9.8	-6.6	-9.1	-6.8	-8.9
E350	% v/v	95.0	92.1	92.0	92.5	92.0	92.4
CN Ind		49.0	49.0	49.0	49.0	49.2	49.0
Polyarom	% m/m	5.7	6.1	5.9	4.7	5.8	4.6
LHV	GJ/t	43.4	43.3	43.3	43.3	43.3	43.3
IBE							
Production	*Mt/a*	*18.9*	*27.1*	*27.1*	*27.0*	*27.1*	*27.0*
Density		0.825	0.840	0.837	0.831	0.837	0.831
Sulphur	ppm	340	340	40	7	40	7
Viscosity	V50	7.5	10.0	9.6	9.0	9.6	9.0
Aromatics	% m/m	28.3	31.4	31.2	29.4	31.0	29.2
Cloud pt	°C	-12.7	-7.4	-6.6	-8.4	-6.8	-8.4
E350	% v/v	95.0	91.0	91.4	91.9	91.4	91.8
CN Ind		49.0	49.0	49.0	49.5	49.0	49.5
Polyarom	% m/m	5.2	6.4	5.5	4.2	5.4	4.2
LHV	GJ/t	43.5	43.3	43.3	43.4	43.4	43.4
ITG							
Production	*Mt/a*	*24.7*	*34.6*	*34.5*	*34.4*	*34.5*	*34.4*
Density		0.821	0.840	0.831	0.822	0.830	0.823
Sulphur	ppm	340	340	40	7	40	7
Viscosity	V50	6.8	9.8	8.3	7.8	8.3	7.8
Aromatics	% m/m	24.3	31.5	28.4	26.4	28.4	26.6
Cloud pt	°C	-10.7	-6.7	-8.1	-12.6	-8.5	-12.4
E350	% v/v	95.0	90.9	91.3	93.4	91.7	93.2
CN Ind		49.0	49.0	49.0	50.3	49.0	50.3
Polyarom	% m/m	4.1	6.3	4.6	3.5	4.5	3.5
LHV	GJ/t	43.6	43.3	43.5	43.6	43.5	43.6
EEU							
Production	*Mt/a*		*8.8*	*8.8*	*8.8*	*8.8*	*8.8*
Density			0.840	0.840	0.834	0.840	0.837
Sulphur	ppm		340	40	7	40	7
Viscosity	V50		10.1	9.7	9.8	9.9	9.9
Aromatics	% m/m		32.7	30.9	27.8	31.7	28.1
Cloud pt	°C		-10.4	-8.4	-7.3	-8.3	-7.0
E350	% v/v		93.6	93.0	91.3	92.6	91.4
CN Ind			49.0	49.0	51.1	49.0	50.6
Polyarom	% m/m		5.8	4.7	4.3	5.1	4.3
LHV	GJ/t		43.3	43.3	43.4	43.3	43.4