impact of a potential reduction of the poly-aromatics content of diesel fuel on the EU refining industry

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ABSTRACT

The cost and CO_2 emissions associated with the reduction of poly-aromatics (PAH) in the EU diesel fuel have been evaluated using the CONCAWE EU refining model.

A reduction of the diesel fuel PAH specification below 8% m/m would require investment in EU refineries up to nearly 9 G€ at 1% m/m. This would also cause refineries to emit additional CO_2, up to 15.9 Mt/a for a 1% m/m limit corresponding to an increase of over 10% of the total refinery emissions in the reference case.

KEYWORDS

Diesel fuel, poly-aromatics, PAH, refinery investment, CO_2 emissions.

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SUMMARY

CONCAWE's RTSG has undertaken this study in order to evaluate the impact that a reduction of the diesel fuel poly-aromatics (PAH) specification would have on the European refining industry. The main issues under study were the costs to the refining industry and the magnitude of the increase of energy requirement and CO_2 emissions, both from the refineries and from a global point of view.

The study was carried out with the CONCAWE EU-wide refining model and encompassed the whole of Europe including EU-25 members, Norway, Switzerland, countries from the former Yugoslavia, Romania and Bulgaria. The model was extensively checked and modified where necessary to provide a sufficiently realistic modelling of PAH as well as of other key properties of diesel fuel.

The PAH content of sulphur-free diesel blending components depends on many factors notably the operating conditions of desulphurisation plants, the severity of operation of cracking units and, to a lesser extent, the crude origin. We have therefore approached the modelling of PAH on the basis of current and forecast levels indicated by a survey of some 30 refineries and after consultations with catalyst technology suppliers.

Reducing PAH in European diesel fuel is technically feasible. As the PAH content of diesel blending components depends on many factors notably the crude origin, the operating conditions of desulphurisation plants and the severity of operation of cracking units, there will still be considerable variations between regions and refineries. The move to the 10 ppm sulphur specification will result in measured values up to 8% m/m, with a reduction of the average measured PAH level to about 4% m/m. As a result of this variability any specification below 8% m/m would entail costs and additional CO_2 emissions for the industry.

If the specification were to fall further below this level, yet more refineries would need to install additional process units, essentially in the form of dedicated de-aromatisation and hydrogen production facilities. This extra step would be costly and would cause a significant increase of the energy consumption and therefore CO_2 emissions of the refineries.

Investment would be required from a specification level of 8% m/m increasing to nearly 9 G€ at 1% m/m. As explained above, the capital expenditure (capex) would essentially be in the form of new hydrodearomatisation and hydrogen production plants. A specification of PAH in diesel fuel below 8% m/m would therefore entail additional costs to the EU refining industry. The total annualised costs would reach 2.2 G€/a for a specification of 1% m/m limit, representing 12.4 €/t of diesel fuel.

A reduction of the diesel fuel PAH specification below 8% m/m would cause refineries to emit additional CO_2, up to 15.9 Mt/a for a 1% m/m limit corresponding to an increase of over 10% of the total refinery emissions in the reference case. Even after accounting for emission reduction due to the lower CO_2 emission factor of the de-aromatised diesel fuel, a net effect of up to 9.2 Mt/a can be expected.

The following table summarises the evolution of costs and CO_2 emissions as a function of the PAH specification level.

PAH specification	% m/m	8.0	6.0	4.5	3.5	2.0	1.0
Capital Investment	M€	14	1278	2627	4748	7538	8762
Annualised costs M€	M€/a	3	312	634	1203	1893	2249
Extra CO_2 emissisons	Mt/a						
From refineries		0.0	1.5	4.2	8.4	13.4	15.9
Net		0.0	0.8	2.4	4.8	7.6	9.2

1. INTRODUCTION

In the context of the Review of the 2000 Road Fuels Directive, scheduled to be completed by the end of 2005, a tightening of the maximum content of poly-aromatics of diesel fuels may be considered.

This study has been undertaken by CONCAWE's Refinery Technology Support Group, with the objective to assess the impact that such a change would have on the EU refining system in terms of extra costs, energy consumption and CO_2 emissions.

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 purpose 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 extra energy usage and hydrogen generation.

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.

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 in 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 not to 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.

The way PAH has been treated is explained in detail in the following sections.

2.3. MODELLING OF SPECIFIC DIESEL FUEL PROPERTIES

2.3.1. PAH

EN 590 specifies a poly-aromatic content of 11% m/m maximum. This refers to molecules with 2+ aromatic-rings further refer to as PAH. EN 590 also specifies the measurement method EN 12916, an HPLC[1] method with refractive index detection.

Modelling of PAH in diesel is notoriously difficult. The PAH content of virgin gasoils is highly dependent on the crude origin. Cracked gasoils and LCO have generally high to very high PAH content, the precise amount depending on the feed origin and the specific severity conditions of the plant. When it comes to the PAH content of a final diesel blend meeting the 10 ppm sulphur limit, the only components of interest are all hydrotreated (or come from hydrocracking processes). It is therefore the likely PAH content of such components that needs to be assessed and fed to the model. Hydrodesulphurisation generally reduces the PAH content of gasoils but the reaction is limited either by kinetics or by thermodynamics (PAH saturation is favoured by a higher hydrogen partial pressure and a lower temperature). At the high severity conditions prevailing to reach the 10 ppm sulphur limit, the thermodynamic limit is reached in most cases. The resulting PAH content of the hydrotreated gasoil will depend on the PAH content of the feed and on the operating conditions of the hydrotreater at the time. Specifically, the PAH content will tend to increase as the catalyst ages and its loss of activity needs to be compensated by an increase in reactor temperature.

As a result of the foregoing the global modelling of PAH in diesel can only be approached on the basis of average actual values. A survey of some 30 EU refineries indicated that the average PAH content of today's diesel blends is in the region of 6% m/m (with fairly large variations), and set to decrease to about 4% m/m by 2010 when all schemes for meeting the 10 ppm sulphur limit have been implemented.

We have set the values for the various diesel components in the model at a level which produces such average PAH levels in the blend. **Table 2** below summarises the values used for untreated stocks as well as treated components at various severity levels.

Table 2a PAH content of key gasoil components (% m/m)

	Untreated	L HDS	M HDS	H HDS	HDA
SR kerosene		1.3-3.0			NA
SR gasoils	10	8	6	4	0.1
Coker & TC gasoils	20	12	8	6	0.1
LCO	40	16	12	8	0.1

L/M/H HDS refer to gasoil hydrodesulphurisation units operating with hydrogen partial pressures of < 30 bar, 30-50 bar and > 50 bar respectively

[1] High Performance Liquid Chromatography

Table 2b PAH content of key gasoil components (% m/m)

Products from hydrocrackers	
kerosene	1
gasoils	
Once-through unit (low/medium conversion)	4
Recycle unit (high conversion)	2
Products from residue conversion processes	
kerosene	2
gasoil	6

It must be well understood that, accordingly, the model will predict that a 4% m/m average PAH level is achieved as a “come along” effect of reducing sulphur to 10 ppm, without further measures and therefore without extra cost. This aspect is further discussed in **Section 3**.

The last column indicates the level of PAH conversion in a hydrodearomatisation (HDA) unit. The HDA process, carried out in a separate unit and usually using a noble metal catalyst, is considered, at the moment, as the only option available to the refiner to further convert PAH.

Catalyst technology development is evolving rapidly. It is likely that new generations of hydrodesulphurisation catalyst will be able to achieve somewhat lower PAH levels, providing that the reactor system has been designed to achieve low enough operating temperatures throughout the cycle and sufficiently high hydrogen partial pressures are available. This may open the possibility of dispensing with separate HDA plants thereby reducing investment costs, at least for the less stringent PAH limit scenarios. The capex savings are, however, likely to be partly compensated by higher opex (catalyst cost). Note that the effect on energy consumption and CO_2 emissions would be minimal, unless it can be established that the selectivity towards PAH compared to monoaromatics saturation is significantly different in the two schemes.

2.3.2. Cetane

The cetane rating of diesel fuels is rarely directly measured. More typically it is 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.

2.4. 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.

2.5. 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 represent by far the largest portion. The latter only become significant in refineries with large hydrocracking or residue hydroconversion facilities although deep dearomatisation of diesel fuel would also noticeably increase them.

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 is balanced. 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.

2.6. 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 a more complex and diverse reality where some refiners will choose trading rather than investment to solve their particular problem. It is considered, 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 arbitrary regions and lumping all refineries together in that region can also appear to be a bold assumption which 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. Meeting a certain PAH specification would generally boil down to converting a certain absolute quantity of PAH present in the diesel fuel pool and there would be 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 AND CASES

3.1. EU ROAD FUELS MARKET AND SUPPLY FROM REFINERIES: REFERENCE CASE

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.

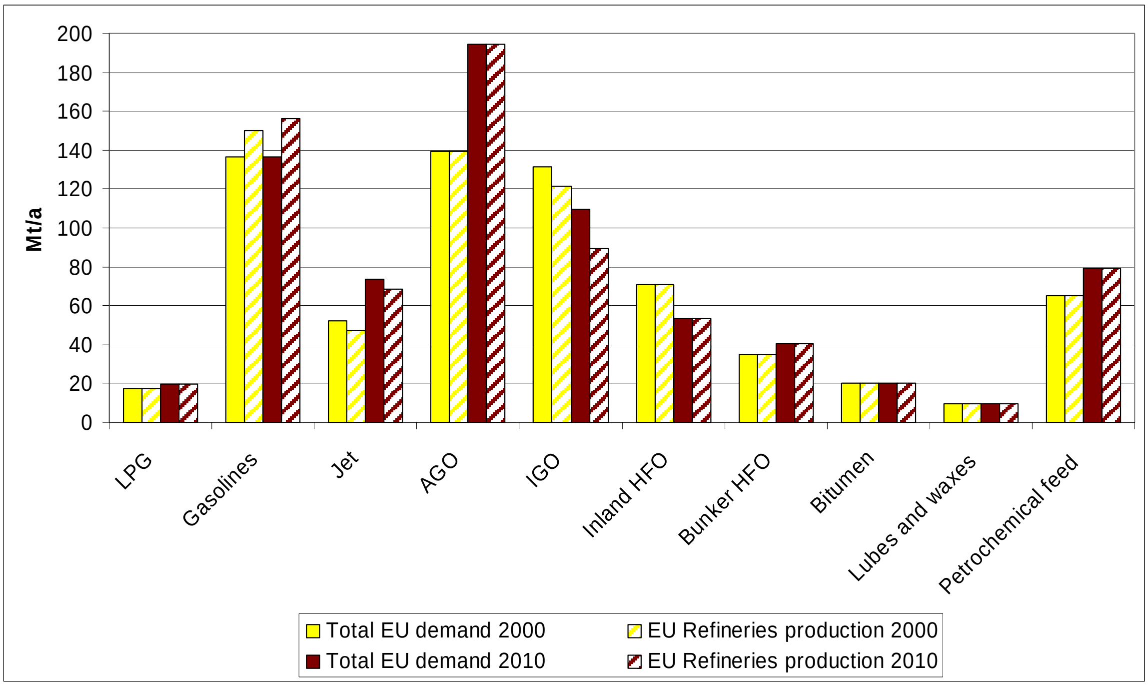
The 2000 road fuels market for the 9 regions under consideration was approximately 135 and 140 Mt for gasoline and diesel fuel respectively. Some 30% of the diesel fuel is consumed by light-duty vehicles. The share of diesel in the total transport fuel demand has been growing for a number of years and 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 1**.

Figure 1 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 and 10 ppm sulphur in both gasoline and diesel fuel.

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 empirical modelling of the PAH content of diesel blending components (see **Section 2.3**) implies that the crude diet is not an essential parameters in this study.

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. REDUCED PAH CASES

Alternative cases include reduction of the PAH content of diesel to various levels. According to the considerations in **Section 2.3**, the model will not react to a reduction down to about 4% m/m as it has been calibrated to deliver that value in the reference scenario. The model was therefore run with decreasing targets of 11 (reference), 4, 3, 2, 1 and 0.5% m/m (these are *not* specification levels, see **Section 3.4**).

Plans to produce 10 ppm sulphur diesel in EU refineries are already well advanced. Investments for PAH reduction would therefore, in most cases, come in addition to those already underway for sulphur-free diesel. This may result in some stranded HDS investment where, for instance, the hydrodearomatisation (HDA) units required for PAH reduction, also remove some of the sulphur. Accordingly we have considered that the plant capacities “installed” in the reference case and not utilised in the low PAH cases do not generate investment credits.

Note that this affect costs but not energy or CO_2 emissions as these are only used or generated when plants are actually utilised.

3.3. ACCOUNTING FOR VARIABILITY BETWEEN REFINERIES

The model target PAH is an average figure that hides a more diverse reality. Each refinery starts from a different situation and will have its own strategy for reaching the 10 ppm sulphur goal. The solutions used will depend on a variety of factors including refinery configuration, crude diet and characteristics of the existing HDS units. As a result each refinery will experience a different relationship between diesel PAH and sulphur content. The combination of 4% m/m PAH and 10 ppm sulphur represents only the best estimate of the European average. Certain refineries will be achieving less than 4% m/m while others will be above this value because of an unfavourable combination of the above factors.

There is no simple way of representing this diversity in the model. If 4% m/m is the refinery production target necessary to meet a certain specification, this latter group of refineries will incur costs which are not captured by the model. Some provision must, therefore, be made in the reporting to account for these additional costs and CO_2 emissions. To represent this, the following assumptions have been adopted:

- The average refinery will reach 4% m/m PAH at 10 ppm sulphur but with a variation amongst refineries of about ± 2% m/m. If the target is 4% m/m, those refineries that do better will not incur extra cost. Those that do worse will need corrective action.
- The distribution of PAH in refineries roughly follows a bell shape with 35% of refineries falling between 4 and 5% m/m PAH, 12% falling between 5 and 6% m/m and 3% between 6 and 7% m/m.
- For the refineries concerned the actions required for reducing from 7, 6 or 5 to 4% m/m would be the same as those envisaged by the model for reducing from 4 to 1, 2 or 3% m/m respectively.

With the simplifying assumption of linearity between the correction points this leads to the following correction for parameter X (e.g. additional cost or CO_2 emissions):

$$X_{cor} = X + 0.5 * (0.35 * \Delta X_{3\text{-}4} + 0.12 * \Delta X_{2\text{-}4} + 0.03 * \Delta X_{1\text{-}4})$$

The correction is then applied to all relevant parameters i.e. new unit capacity (and cost), additional energy requirement and CO_2 emissions.

The same correction was applied to the 3% m/m case (now based on the 2, 1 and 0.5% m/m cases). For the 2% and 1% m/m cases the correction was reduced by half, reasoning that, at these levels, the variability between refineries would be significantly reduced because, with more and more HDA units in place, tighter PAH control would be possible.

3.4. PRODUCT SPECIFICATION VERSUS ACTUAL PRODUCTION TARGET

Refineries must meet product specifications. The PAH figures discussed above refer to refinery production targets. In practice, a refinery that has to meet a constraining specification will attempt to be as close as possible to the limit value without delivering off-spec products or having to carry out re-blending operations on a regular basis. This results in the application of a blending margin being the difference between the specification and the internal refinery blending target. This margin is selected on the basis of a number of factors specific to the refinery production and blending scheme and also taking into account the precision of the analytical method.
As a result the production target is always more constraining than the specification. The blending margin needs to be assessed in order to relate the costs and emissions associated with a certain production target to a specification.

3.4.1. Process variability within a refinery

A typical refinery producing low sulphur and even 10 ppm sulphur diesel will not have a separate mechanism to control PAH. The HDS plants will be run to meet the sulphur limit and PAH will be resultant. The actual level achieved will depend on the feed type, the unit process parameters (hydrogen partial pressure, space velocity) and the activity of the catalyst (which will decrease during a cycle). The only practical option for the refiner would be to limit the cycle length in order to avoid an increase of PAH when the reactor temperature needs to be increased beyond the point where the thermodynamic equilibrium limits PAH conversion. Only the availability of a separate HDA unit provides the extra degree of freedom to properly control PAH.

As a result, it is likely that PAH levels will vary significantly over time within a refinery even when it produces 10 ppm diesel. Only low PAH targets, maybe below 2% m/m would force HDA units in and decrease this variability.

We have estimated this process variability could be up to ±2% m/m at the 4% m/m level.

3.4.2. Analytical method

PAH determination is a relatively new analytical endeavour. The latest recommended method EN 12916 has a better precision than previous ones but variability remains. Its repeatability (r) and reproducibility (R) depend on the absolute PAH level according to the following formulae:

$$r = 0.11 \times PAH$$
$$R = 0.32 \times PAH$$

(Valid for 0 to 12% m/m)

Taking a conservative stance vis-à-vis ASTM D4259 (which codifies practices related to product release and acceptance) one can calculate release targets that would guarantee an on-spec product with 95% confidence (this requires the release target to be set 0.59*R below the specification).

Table 3 Release margin due to analytical method

PAH spec %m	r	R	0.59*R	Release target
8.0	0.88	2.56	1.51	6.5
6.0	0.66	1.92	1.13	4.9
4.5	0.50	1.44	0.85	3.7
3.5	0.39	1.12	0.66	2.8
2.0	0.22	0.64	0.38	1.6
1.0	0.11	0.32	0.19	0.8

3.4.3. Proposed margin between specification and refinery target

The two above effects are statistically independent and therefore not additive. For the purpose of this evaluation, we have used the following pragmatic margins.

Table 4 PAH specification and refinery production target

PAH spec %m/m	**Margin**	**Refinery production target**
8.0	2.0	6.0
6.0	2.0	4.0
4.5	1.5	3.0
3.5	1.5	2.0
2.0	1.0	1.0
1.0	0.5	0.5

4. STUDY 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. 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 diesel fuel quality. More detailed results are available in **Appendix 3** for the total EU as well as for individual regions.

4.1. ADDITIONAL CAPACITY, MECHANISM FOR PAH REDUCTION

PAH removal is a single issue which can be addressed by a combination of hydrotreating and HDA. The options selected by the model reflect this.

Table 5 gives a summary, for the main units affected, of required new capacity. Negative figures for the medium pressure gasoil hydrodesulphurisers (GO HT MP) denote revamped capacity that would have been installed in the reference case to reach 10 ppm and would not be used in the corresponding reduced PAH scenario (i.e. the "regret investment").

Note that **Table 5** as well as **Table 6** in the next section relate directly to specific runs of the model. They therefore do not include the corrections discussed in **Section 3.3**.

Table 5 Additional plant capacity requirement

	Used capacity Mt/a				
PAH specification	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model	4.0	3.0	2.0	1.0	0.5
	Additional from reference				
Kero HT	3.0	3.7	6.6	4.6	1.5
GO HT LP					
GO HT MP revamp	-2.4	-4.4	-16.5	-23.4	-18.5
GO HT HP					
GO HDA	2.6	17.1	52.7	101.6	129.2
Hydrogen manuf (as hydrogen) (1)	*17*	*63*	*232*	*416*	*510*
Hydrogen scavenging (1)	*11*	*36*	*40*	*43*	*48*

(1) Capacities expressed in kt/a

The PAH control mechanism is the progressive introduction of gasoil HDA as the specification becomes more stringent. At the extreme of 0.5% m/m PAH, there would be one HDA unit in every refinery. There is also a sizeable reduction of gasoil HDS utilisation as the HDAs take over some of the sulphur removal duty of the HDSs (high pressure HDSs are particularly backed out). The model also requires some other small changes to "balance the books" (see **Appendix 3** for details).

Note that, in practice, facilities already installed to produce 10 ppm sulphur could also continue to be used as such, thereby reducing somewhat the cost of the additional HDA unit.

4.2. INVESTMENT COSTS

Table 6 shows the investment costs for the above new capacities.

Table 6 Investment in new plants (MEUR)

	Capex M€				
PAH specification	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model	4.0	3.0	2.0	1.0	0.5
	Additional from reference				
Kero HT	135	167	286	206	78
GO HT LP					
GO HT MP revamp					
GO HT HP					
GO HDA	169	1072	3176	5880	7359
Hydrogen manuf (as hydrogen) (1)	28	105	390	703	865
Hydrogen scavenging (1)	14	46	51	55	62
Total (2)	**807**	**1731**	**4315**	**7363**	**8762**

(1) Capacities expressed in kt/a

(2) Including all units, no credit for unused capacity

Note: Only main units shown. The "Total" row includes units not shown; see **Appendix 3** for details

Depending on the specification level envisaged, reduction of the PAH content of diesel fuel would require between investment of 0.8 G€ at the 6% m/m level and nearly 9 G€ at 1% m/m. The majority of the capex would be for new hydrodearomatisation plants and hydrogen production plants.

4.3. ENERGY USAGE AND CO_2 EMISSIONS

Reducing the PAH level of AGO requires additional energy to drive the new process units and also to produce the extra hydrogen required to saturate the aromatic rings. This contributes to higher CO_2 emissions from the site whereas hydrogen manufacture also produces "chemical" CO_2 corresponding to the decarbonisation of the hydrocarbon feedstock.

However, the AGO produced has a lower carbon to hydrogen ratio as well as a higher heating value As a result less CO_2 is released per unit energy when burned i.e. for a given "transport" demand. This generates a CO_2 credit which is reflected in **Table 7**. The carbon/hydrogen ratio and heating value of other fuel products may also change slightly from one case to another as the model adjusts blend compositions as part of the optimisation process.

Note that the figures presented in this and the next section include the correction to represent the variability between refineries (see **Section 3.3**). Accordingly the tables show CO_2 emissions and costs beginning to appear from a specification of 8% m/m and an estimated target value of 6% m/m.

Table 7 Energy and CO_2 emissions

	Reference	Alternatives					
PAH specification	**11.0**	**8.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model	11.0	6.0	4.0	3.0	2.0	1.0	0.5
From site	**161.7 (*)**	**0.03**	**1.5**	**4.2**	**8.4**	**13.4**	**15.9**
From fuel products	2027.5	-0.01	-0.7	-1.8	-3.6	-5.7	-6.7
From import/export	-11.3	0.00	0.0	0.0	0.0	0.0	0.0
Net	**2016.2**	**0.02**	**0.8**	**2.4**	**4.8**	**7.6**	**9.2**
Diesel fuel production for EU market (Mt/a) [(1)]	*182.5*	*182.5*	*182.4*	*182.1*	*181.8*	*181.5*	*181.4*
kg CO2 per tonne of fuel		**0.2**	**8.3**	**23.0**	**46.3**	**73.6**	**87.8**

(*) 146 when excluding petrochemicals
(1) Excluding Eastern grade

Approximately 40% of the extra CO_2 produced in the refinery is recovered as a credit when burning the fuels.

In a carbon-constrained world the extra CO_2 emissions from the site have a cost equal to that of the extra emission permits to be purchased. The cost summary in the next section includes this.

Note: the decrease of diesel tonnage with decreasing PAH corresponds to the increase in heating value, yielding constant energy.

A reduction of the diesel fuel PAH specification below 8% m/m would cause refineries to emit additional CO_2, up to 15.9 Mt/a for a 1% m/m limit, corresponding to an emissions increase of over 10% of the total refinery emissions in the reference case.

Even after accounting for emission reduction due to the lower CO_2 emission factor of the diesel fuel, a net effect of up to 9.2 Mt/a can be expected.

4.4. COST SUMMARY

The estimation of the total cost of reducing PAH needs to reflect the following elements:

Cost of capital This is represented by a yearly capital charge of 15% of the capex, broadly corresponding to an 8% IRR which is the minimum level of return commonly accepted in the industry.

Operating costs The extra operating costs essentially stem from new units for which we use a yearly charge of 4.3% of the capex.

Any extra costs e.g. for catalysts or additives also need to be accounted for in this section. Catalyst costs are linked to utilisation of hydrotreating and HDA plants. No extra additives have been deemed to be required (e.g. lubricity additive is already required in the reference case).

Margin loss This is calculated by the model as the reduction of the gross margin of the refineries. A reference crude price of 25 $/bbl has been used. The main component of this is the extra fuel and loss incurred by the refineries for the extra processing.

Inter-regional transfers Some additional transfers are required which are also charged by the model at a nominal cost of 15 €/t.

CO_2 emissions The cost of purchasing CO_2 emission permits will not be known until a market is established. An illustrative figure of 20 €/t CO_2 has been used.

The total cost summary is shown in **Table 8** and **Figure 2**, based on the model figures corrected for the variability between refineries.

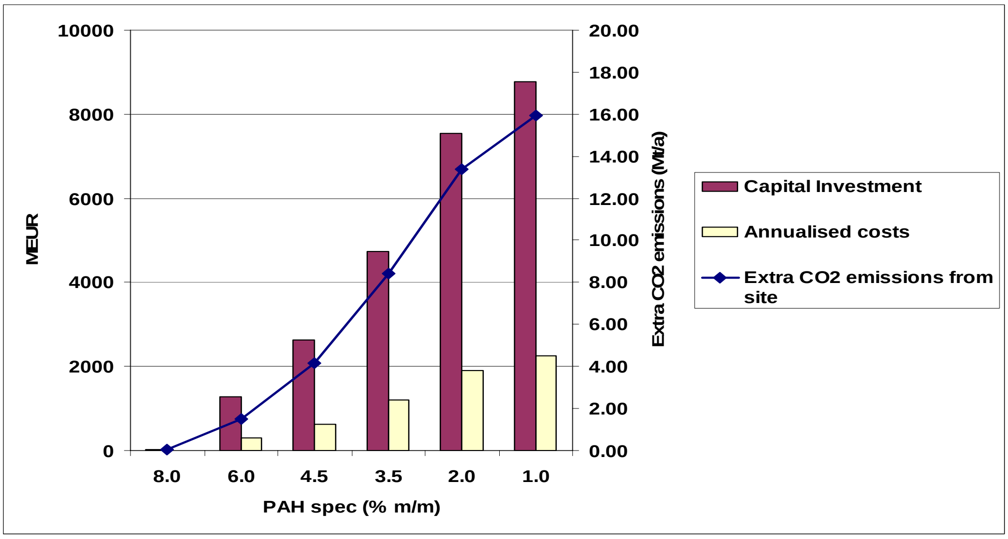
Table 8 Cost summary

PAH specification		**8.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		6.0	4.0	3.0	2.0	1.0	0.5
Capital Investment	M€	**14**	**1278**	**2627**	**4748**	**7538**	**8762**
Capital Charge @15%		2	192	394	712	1131	1314
Opex	M€/a	**1**	**82**	**130**	**275**	**419**	**521**
Of which CO_2 emissions		0	30	84	168	267	318
Margin loss [(1)]		**0**	**38**	**109**	**216**	**343**	**413**
Annualised costs	M€/a	**3**	**312**	**634**	**1203**	**1893**	**2249**
NPV [(2)]	G€	**0.0**	**2.5**	**5.0**	**9.5**	**15.0**	**17.9**
Diesel fuel production for EU market	*Mt/a*	*182.5*	*182.4*	*182.1*	*181.8*	*181.5*	*181.4*
Cost per tonne of Diesel fuel	€/t	**0.0**	**1.7**	**3.5**	**6.6**	**10.4**	**12.4**

[(1)] Mainly due to additional Fuel & Loss

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

Figure 2 Cost and CO_2 emissions summary



In order to reduce PAH in diesel fuel below 8% m/m, the EU refining industry would incur additional costs. The total annualised costs would reach 2.2 G€/a for a specification of 1% m/m, representing 12.4 €/t of diesel fuel.

4.5. DIESEL QUALITY

Reduction of the PAH is done at constant sulphur and the model has enough degrees of freedom to achieve this. Other properties are affected to varying degrees depending on the grade considered. **Table 9** gives a summary of the changes for the European aggregate of each the three EU AGO grades.

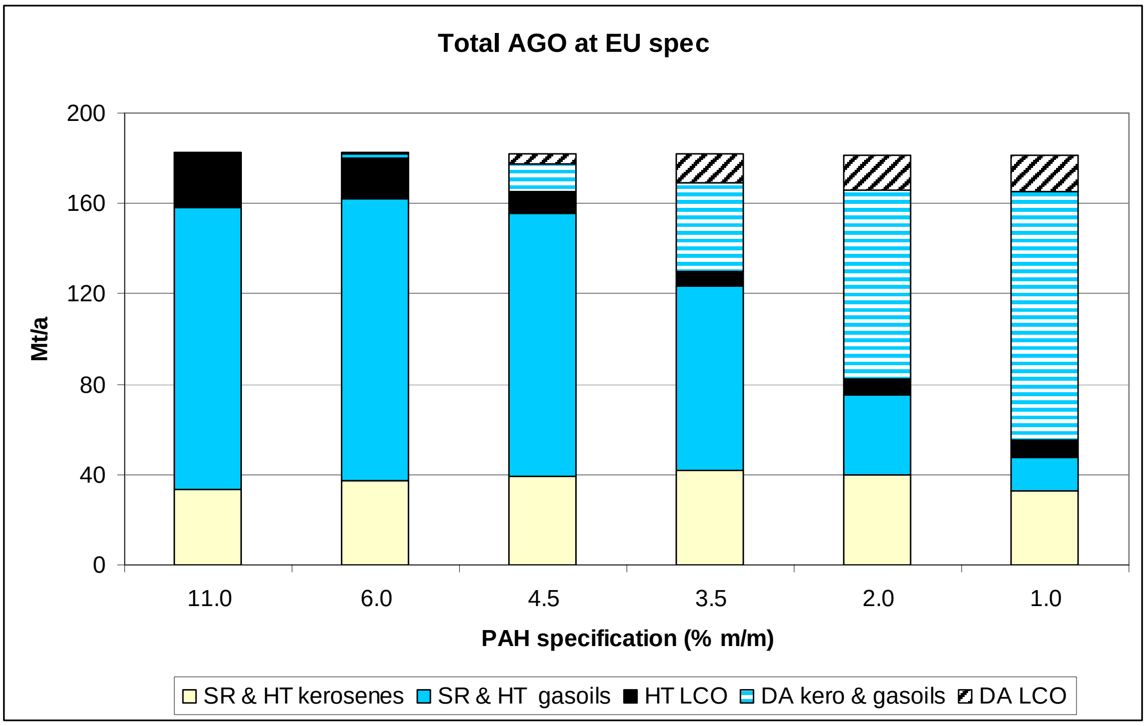
Table 9 EU average AGO quality at decreasing PAH levels

		Reference	Alternatives				
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5
Total AGO (@ EU spec)							
Production	*Mt/a*	*182.5*	*182.4*	*182.1*	*181.8*	*181.5*	*181.4*
Density		0.831	0.831	0.826	0.823	0.821	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	28.7	27.4	23.8	19.2	13.9	11.1
Cloud pt	°C	-8.3	-8.4	-8.6	-6.4	-6.0	-6.0
CN Ind		50.3	50.5	50.9	50.3	51.0	51.8
LHV	GJ/t	43.4	43.4	43.5	43.6	43.7	43.7
AGO North							
Production	*Mt/a*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.3*
Density		0.827	0.827	0.827	0.826	0.823	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	27.6	27.0	24.7	20.2	15.2	12.3
Cloud pt	°C	-11.0	-10.4	-11.9	-7.5	-7.5	-7.5
CN Ind		49.0	49.0	49.0	49.0	49.0	50.2
LHV	GJ/t	43.4	43.4	43.4	43.5	43.6	43.6
AGO Middle							
Production	*Mt/a*	*88.8*	*88.8*	*88.6*	*88.4*	*88.3*	*88.2*
Density		0.835	0.834	0.829	0.825	0.822	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	29.2	26.9	23.3	18.6	13.7	10.9
Cloud pt	°C	-6.0	-6.0	-6.3	-5.0	-5.4	-5.7
CN Ind		51.0	51.0	51.4	51.2	51.6	52.4
LHV	GJ/t	43.4	43.4	43.5	43.6	43.7	43.7
AGO South							
Production	*Mt/a*	*78.2*	*78.2*	*78.1*	*78.0*	*77.9*	*77.9*
Density		0.828	0.828	0.823	0.821	0.820	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	28.4	28.0	24.1	19.6	13.7	11.0
Cloud pt	°C	-10.4	-10.7	-10.5	-7.7	-6.4	-6.0
CN Ind		49.7	50.1	50.8	49.6	50.9	51.4
LHV	GJ/t	43.5	43.5	43.6	43.6	43.7	43.7

The total aromatics content is gradually reduced, particularly for the lower PAH levels where massive use of HDA occurs. As would have been expected density decreases and cetane increases. The latter is, however, also influenced by other factors such as the need to use cracked gasoils to either improve cold properties (as in AGO North), to produce the required AGO volumes or to simply to dispose of such streams in areas without substantial heating oil markets (e.g. Southern Europe).

Figure 3 further depicts the average composition of the AGO blends, again on a pan-European basis.

Figure 3 Average composition of AGO blends



In the reference case the blends essentially consist of straight-run gasoils supplemented by kerosene and some LCO (all hydrotreated of course). As the PAH limit decreases, the de-aromatised components appear gradually, to form the bulk of the blend at very low PAH.

These European averages of course hide a diversity of specific situations. The details of AGO blend qualities for each of the 9 regions can be found in **Appendix 3**.

This evaluation is based on a single refinery representing the whole industry in a region. There will also be significant differences between the actual refineries within that region stemming from local circumstances including feedstocks, configuration and hydrotreating units design with different pressure levels, catalyst volumes and operating limits.

5. CONCLUSIONS

Reducing PAH in European diesel fuel is technically feasible. The move to the 10 ppm sulphur specification will result in a reduction of the average PAH level to about 4% m/m although there will still be considerable variations between regions and refineries and also within refineries when crude diet, catalyst activity and other process conditions change.

Because of this variability, some costs (and extra CO_2 emissions) would be gradually incurred for specification levels under 8% m/m.

To reduce PAH below the level achieved by desulphurisation, refineries would need to install additional process units, essentially in the form of dedicated de-aromatisation facilities. This extra step would be costly and would cause a significant increase of the energy consumption and therefore CO_2 emissions of the refineries.

At an extreme specification level of 1% m/m annual costs to the EU refining industry would be in the order of 2.25 billion euros while the refineries would emit an additional 15.9 Mt/a of CO_2, representing an increase of over 10%. After accounting for the reduced CO_2 emissions of the fuels produced the net additional CO_2 emissions would still be in the order of 9 Mt/a.

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€ and are meant to include both ISBL and OSBL costs).

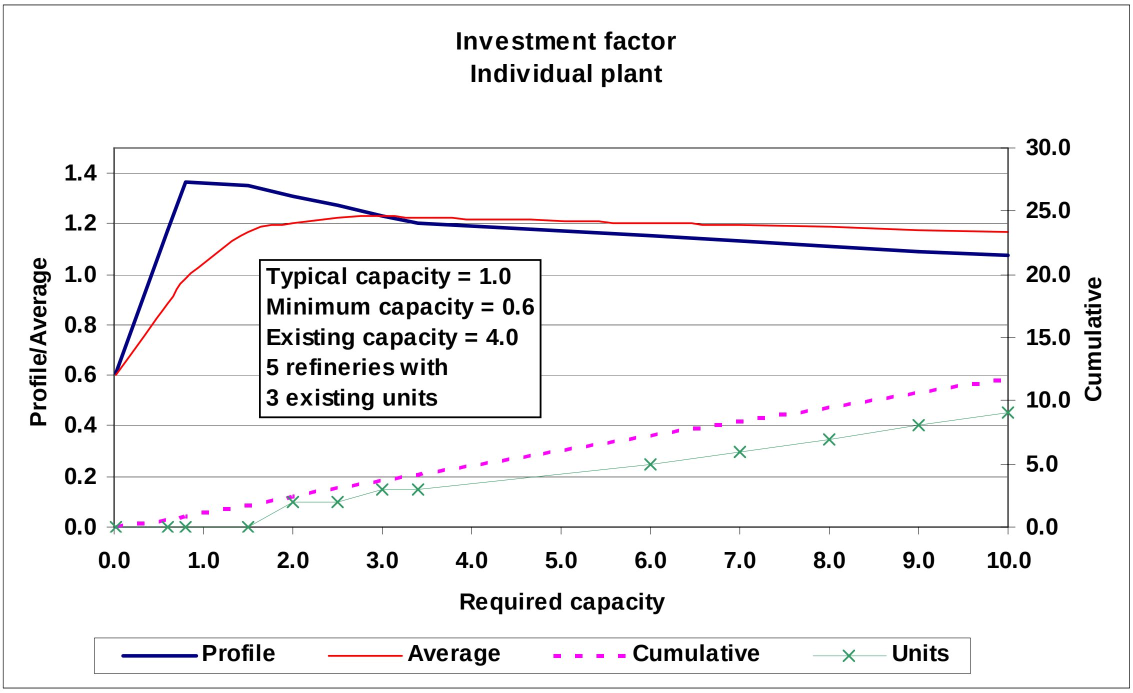
Plant	Capex	Capacity (Mt/a)
Kerosene hydrotreater	30	0.90
HP gasoil HDS	75	1.30
Gasoil hydro de-aromatisation (HDA)	60	1.30

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 tonne 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.



APPENDIX 2 FEEDSTOCKS, PRODUCT DEMAND AND SPECIFICATIONS

Crude supply

	Mt/a	%
Brent blend	333	43.7
Nigerian Forcados	77	10.2
Algerian condensate	2	0.3
Total LS crude	**412**	**54.2**
Urals (Russian export blend)	87	11.4
Iranian light	158	20.7
Kuwait (1)	105	13.7
Total HS crude	**349**	**45.8**
Total crude	**762**	

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

Product specifications and model quality target

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

(1) Only for SEU region

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

(3) from 0 to -7.5 depending on region

Call on refineries (reference case)

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	156.3	9.8	24.1	14.7	26.5	19.4	14.4	26.2	10.6	10.7
Reg 92	*4.4*	*0.0*	*0.0*	*0.0*	*4.0*	*0.0*	*0.0*	*0.4*	*0.0*	*0.0*
Super 95	*112.2*	*8.9*	*22.1*	*10.9*	*21.1*	*10.6*	*9.0*	*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*	*6.1*	*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	194.2	11.0	23.3	22.6	33.3	20.9	27.0	35.1	8.8	12.3
North	*15.4*	*11.0*	*0.0*	*0.0*	*4.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Middle	*88.8*	*0.0*	*23.3*	*22.6*	*28.8*	*5.3*	*0.0*	*0.0*	*8.8*	*0.0*
South	*78.2*	*0.0*	*0.0*	*0.0*	*0.0*	*15.6*	*27.0*	*34.4*	*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	89.8	11.3	5.0	9.8	18.6	14.0	5.7	12.4	10.1	3.0
North	*11.9*	*9.7*	*0.0*	*0.0*	*2.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Middle	*40.6*	*0.0*	*3.1*	*5.8*	*14.4*	*7.2*	*0.0*	*0.0*	*10.1*	*0.0*
South	*34.5*	*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	4.5	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	*45.2*	*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	79.3	4.2	4.7	17.2	17.9	11.5	6.0	10.6	4.0	3.2

Material balance (reference case)

	Total	SCA	UKI	BEN	MEU	FRA	IBE	ITG	EEU	SEU
In										
Crude	761.52	51.48	94.86	97.59	114.69	95.90	83.84	135.38	46.50	41.28
LS	412.50	37.46	73.67	52.37	68.62	61.50	45.62	51.32	21.22	0.71
HS	349.02	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	1.99	0.00	1.42	5.22	2.24	0.00	0.00	0.24	1.12
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	0.19	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
MTBE	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
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	0.82	0.01	0.00	0.08	0.43	0.04	0.07	0.15	0.04	0.00
Out										
Main products										
LPG	19.56	2.07	2.44	1.72	1.67	3.47	2.74	2.83	1.67	0.95
Gasolines	156.33	9.84	24.07	14.66	26.53	19.39	14.36	26.21	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	194.19	10.96	23.33	22.58	33.29	20.92	27.04	35.07	8.75	12.25
IGO + gasoil comp.	92.82	11.28	6.99	9.78	18.62	14.01	5.67	13.33	10.10	3.04
LSFO	58.79	7.26	8.09	9.86	7.54	7.86	5.22	8.37	4.39	0.21
HSFO	35.15	0.00	1.43	8.01	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	5.80	3.60	1.97	3.41	1.29	1.01
Propylene	17.96	1.04	1.33	3.30	3.73	2.68	1.52	2.49	0.91	0.96
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	0.54	0.91	1.99	2.25	1.10	1.46	1.38	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	3.70	0.16	0.33	0.53	0.74	0.32	0.34	0.77	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	7.80	0.04	1.14	0.31	1.25	0.17	0.23	2.76	1.23	0.67
Refinery fuel										
Gas	26.04	1.46	3.40	3.86	4.90	3.08	2.30	4.51	1.15	1.39
Liquid	14.04	1.05	0.94	1.31	2.54	1.76	2.04	2.21	1.60	0.58
Solid	6.54	0.37	1.28	0.61	0.96	0.97	0.60	0.84	0.30	0.61

APPENDIX 3 NEW UNIT CAPACITY AND INVESTMENT

Totals for EU-25 + Norway & Switzerland

	Used capacity Mt/a							Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
EU-25+2													
CDU	743.07	10.38	14.97	14.69	14.35	12.09	13.95	72	107	105	103	87	100
HVU	298.92	2.10	4.07	3.79	4.23	3.48	3.61	21	43	40	45	36	38
Visbreaker	78.02												
Del coker	25.92												
C4 deasphalting													
FCC	118.51	0.50	0.45	0.43	0.11	0.09	0.27	46	42	39	9	7	23
Cracked gasoline splitter	7.38	32.18	31.72	31.64	31.71	31.82	32.34	308	304	303	304	305	309
HCU recycle	6.29												
HCU once-through	35.81	2.12	3.89	2.45	2.61	3.09	0.80	280	595	369	371	448	82
Cat feed HT	35.36	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
LR HDS	5.30												
Resid hydroconversion	2.86												
Naph HT	139.99												
Cracked gasoline HT	1.99	24.90	25.13	24.07	22.90	23.18	24.11	1812	1828	1755	1675	1697	1762
Cracked gasoline sweetening		3.89	4.42	4.17	4.44	4.60	3.63	236	266	251	269	278	221
Cat reforming revamp								689	675	673	685	686	699
Cat reforming (LP)	31.90	2.69	2.30	3.50	3.97	3.80	3.83	351	292	469	542	520	524
Reformate splitter	42.84	2.31	2.52	2.46	2.13	2.20	2.17	46	50	49	43	45	45
Light reformate splitter	8.17	1.32	1.43	1.46	1.43	1.40	1.30	39	42	42	42	41	38
Aromatics Extraction	5.55	1.52	1.57	1.61	1.71	1.67	1.62	105	107	111	119	116	113
Alkylation	8.39	0.08	0.09	0.09	0.09	0.08	0.17	29	31	31	30	29	62
Isomerisation once-through	1.47	0.60	0.58	0.58	0.58	0.61	0.62	92	89	89	89	93	94
Isomerisation recycle	17.37	0.47	0.59	0.58	0.52	0.49	0.50	97	126	125	109	102	104
MTBE	2.55	0.53	0.52	0.51	0.49	0.50	0.56	247	244	243	229	233	258
TAME	0.44	2.38	2.38	2.38	2.39	2.40	2.30	370	370	370	371	373	358
Butamer	2.16												
PP splitter	3.94	0.55	0.54	0.55	0.55	0.55	0.54	99	98	99	100	100	99
Kero HT		30.15	33.17	33.78	36.72	34.72	31.94	1314	1450	1477	1597	1520	1407
GO HT LP	32.30												
GO HT MP revamp								2580	2500	2435	2035	1809	1971
GO HT HP	3.80												
GO HDA			2.64	17.13	52.45	100.99	128.19		169	1072	3157	5839	7298
SRU (as sulphur)	3.49	0.47	0.46	0.48	0.49	0.54	0.54	260	264	257	257	292	293
FGDS	1.09	1.99	2.02	1.99	1.98	1.98	2.10	418	424	418	416	416	440
Bitumen	25.95	0.47	0.47	0.47	0.47	0.47	0.47	18	18	18	18	18	18
Lubs	7.84												
Hydrogen manuf (as hydrogen) (1)	*212*	*286*	*302*	*348*	*517*	*702*	*795*	501	528	605	891	1204	1366
Hydrogen scavenging (1)	*52*	*240*	*251*	*277*	*280*	*279*	*281*	323	337	370	373	372	374
POX + GT													
IGCC	2.01	3.18	3.15	3.15	3.13	3.17	3.17	2474	2452	2455	2436	2471	2465
POX + hydrogen	0.12												
POX + methanol	0.39												
Steam cracker	63.34	12.79	12.78	12.85	12.83	12.84	12.89	2569	2573	2605	2622	2638	2649
hydrodealkylation	1.07												
Total								**15397**	**16025**	**16875**	**18936**	**21777**	**23210**

(1) Capacities expressed in kt/a

Scandinavia

	Used capacity Mt/a							Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
SCA: Scandinavia													
CDU	53.78												
HVU	18.65												
Visbreaker	7.66												
Del coker	7.66												
C4 deasphalting													
FCC	6.77	0.50	0.45	0.43	0.11	0.09	0.27	46	42	39	9	7	23
Cracked gasoline splitter	0.73	1.67	1.66	1.70	1.68	1.61	1.72	16	16	17	17	16	17
HCU recycle													
HCU once-through	3.39												
Cat feed HT	2.35												
LR HDS													
Resid hydroconversion													
Naph HT	10.38												
Cracked gasoline HT		1.71	1.70	1.73	1.72	1.67	1.73	125	125	126	126	123	127
Cracked gasoline sweetening		0.02	0.03	0.02	0.02	0.04	0.03	2	2	1	2	3	2
Cat reforming revamp								3	3	4	4	2	6
Cat reforming (LP)	3.91												
Reformate splitter	2.30	0.30	0.29	0.23	0.17	0.05		4	4	3	2	1	
Light reformate splitter	0.33	0.26	0.25	0.27	0.23	0.25	0.24	7	7	7	6	7	6
Aromatics Extraction		0.34	0.43	0.37	0.39	0.40	0.34	26	32	28	29	31	26
Alkylation	0.47												
Isomerisation once-through													
Isomerisation recycle	1.92												
MTBE	0.17	0.03	0.03	0.03	0.02	0.02	0.02	13	13	13	9	8	11
TAME													
Butamer													
PP splitter	0.21	0.08	0.07	0.07	0.06	0.06	0.07	13	13	13	11	10	12
Kero HT		3.52	3.60	3.37	3.20	3.25	1.94	155	158	149	142	144	88
GO HT LP	5.28												
GO HT MP revamp								140	137	146	126	118	140
GO HT HP													
GO HDA					2.03	5.21	7.43				128	317	441
SRU	0.16	0.01	0.01	0.01	0.01	0.00	0.00	2	1	2	1	1	0
FGDS		0.16	0.16	0.16	0.16	0.16	0.16	33	33	33	33	33	33
Bitumen	2.84												
Lubs	0.13												
Hydrogen manuf (as hydrogen) (1)		*8*	*6*	*7*	*20*	*32*	*41*	13	10	13	34	55	71
Hydrogen scavenging (1)	*8*	*16*	*16*	*16*	*16*	*16*	*16*	21	22	22	22	22	22
POX + GT													
IGCC													
POX + hydrogen													
POX + methanol													
Steam cracker	4.21												
hydrodealkylation	0.07												
Total								**622**	**619**	**617**	**701**	**898**	**1025**

(1) Capacities expressed in kt/a

UK & Ireland

		Used capacity Mt/a						Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
UKI: UK & Ireland													
CDU	91.16	3.70	3.91	4.12	4.12	4.59	4.44	25	27	28	28	32	31
HVU	43.37												
Visbreaker	3.19												
Del coker	3.97												
C4 deasphalting													
FCC	24.08												
Cracked gasoline splitter	0.80	4.65	4.62	4.61	4.57	4.46	4.66	45	44	44	44	43	45
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	5.83	5.84	5.35	4.85	4.56	4.74	411	411	379	346	327	339
Cracked gasoline sweetening					0.30	0.34	0.29				20	22	19
Cat reforming revamp								23	23	27	29	26	38
Cat reforming (LP)	4.47	0.52	0.43	0.86	0.91	1.11	0.91	55	43	107	115	149	115
Reformate splitter	8.37												
Light reformate splitter	2.39												
Aromatics Extraction	0.96	0.12	0.14	0.13	0.13	0.14	0.13	6	8	7	7	8	7
Alkylation	1.97												
Isomerisation once-through													
Isomerisation recycle	2.85												
MTBE	0.25	0.44	0.44	0.44	0.42	0.42	0.44	214	216	216	205	207	215
TAME													
Butamer	1.89												
PP splitter	0.83	0.09	0.10	0.10	0.11	0.10	0.10	13	14	14	17	15	14
Kero HT			1.16	0.97	1.31	1.16	1.58		53	44	60	53	72
GO HT LP	1.31												
GO HT MP revamp								314	287	283	196	128	106
GO HT HP	2.96												
GO HDA			1.04	3.89	9.44	15.42	18.23		66	241	551	870	1015
SRU	0.35	0.01		0.00		0.00		3		1		0	
FGDS		0.28	0.27	0.28	0.31	0.32	0.36	58	57	59	65	66	75
Bitumen	3.05												
Lubs	1.06												
Hydrogen manuf (as hydrogen) [1]				*1*	*25*	*43*	*52*			2	43	74	90
Hydrogen scavenging [1]		*16*	*28*	*52*	*53*	*54*	*54*	22	37	68	69	70	70
POX + GT													
IGCC		1.17	1.14	1.13	1.12	1.12	1.11	916	896	886	879	879	874
POX + hydrogen													
POX + methanol													
Steam cracker	3.96	0.73	0.68	0.69	0.69	0.68	0.73	140	128	132	132	130	141
hydrodealkylation	0.07												
Total								**2245**	**2312**	**2538**	**2806**	**3098**	**3266**

[1] Capacities expressed in kt/a

Benelux

		Used capacity Mt/a						Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
BEN: Benelux													
CDU	97.31	0.28		0.13				2		1			
HVU	38.64												
Visbreaker	8.87												
Del coker	2.14												
C4 deasphalting													
FCC	11.79												
Cracked gasoline splitter	2.06	0.84	0.89	0.76	0.88	0.90	0.92	9	9	8	9	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	2.32	2.34	2.30	2.30	2.29	2.29	166	168	165	165	164	164
Cracked gasoline sweetening		0.29	0.30	0.26	0.30	0.29	0.32	19	19	16	19	19	20
Cat reforming revamp								26	24	24	24	24	24
Cat reforming (LP)	7.33												
Reformate splitter	3.77												
Light reformate splitter	0.75												
Aromatics Extraction	1.26	0.32	0.33	0.32	0.32	0.33	0.34	21	22	21	21	21	22
Alkylation	0.72												
Isomerisation once-through													
Isomerisation recycle	0.34												
MTBE	0.26	0.02	0.02	0.02	0.02	0.02	0.02	6	6	6	7	7	6
TAME													
Butamer													
PP splitter	0.37	0.04	0.04	0.04	0.05	0.05	0.05	9	9	9	10	10	10
Kero HT		4.19	4.27	4.23	3.95	4.18	3.70	181	184	183	171	181	161
GO HT LP	7.41												
GO HT MP revamp								263	262	242	197	153	181
GO HT HP													
GO HDA				1.58	6.74	12.80	15.80			100	400	727	882
SRU	0.86												
FGDS													
Bitumen	2.20												
Lubs	0.61												
Hydrogen manuf (as hydrogen) [(1)]	*119*					*5*	*16*					14	41
Hydrogen scavenging [(1)]	*2*	*38*	*38*	*38*	*38*	*38*	*38*	50	50	50	50	50	50
POX + GT													
IGCC													
POX + hydrogen													
POX + methanol													
Steam cracker	14.80	2.40	2.32	2.74	2.74	2.76	2.73	443	425	531	532	537	529
hydrodealkylation	0.25												
Total								**1193**	**1177**	**1357**	**1605**	**1916**	**2100**

[(1)] Capacities expressed in kt/a

Mid-Europe

		Used capacity Mt/a						Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
MEU: Mid-Europe													
CDU	130.57												
HVU	52.89	0.82	2.36	2.05	2.42	1.84	1.96	8	24	21	25	19	20
Visbreaker	14.61												
Del coker	7.10												
C4 deasphalting													
FCC	19.60												
Cracked gasoline splitter	0.84	8.99	9.00	9.00	9.00	9.00	9.00	83	83	83	83	83	83
HCU recycle													
HCU once-through	8.39	1.31	3.88	2.45	2.19	2.58	0.67	166	594	369	326	391	70
Cat feed HT	12.60												
LR HDS													
Resid hydroconversion													
Naph HT	26.69												
Cracked gasoline HT		3.58	3.18	3.66	3.35	3.33	3.25	263	236	269	248	246	241
Cracked gasoline sweetening		1.64	1.62	1.77	1.67	1.61	1.61	98	96	105	99	96	96
Cat reforming revamp								382	370	361	373	381	384
Cat reforming (LP)	8.38												
Reformate splitter	5.48												
Light reformate splitter	0.96	0.66	0.68	0.65	0.66	0.70	0.72	20	21	20	20	21	22
Aromatics Extraction	1.70												
Alkylation	1.22												
Isomerisation once-through	0.14												
Isomerisation recycle	4.03												
MTBE	0.47	0.01	0.01	0.01	0.01	0.01	0.01	3	3	3	3	3	3
TAME		1.68	1.68	1.68	1.68	1.68	1.68	261	262	262	262	261	261
Butamer													
PP splitter	0.69	0.02	0.02	0.02	0.02	0.02	0.02	3	3	3	3	3	3
Kero HT		1.73	2.40	3.54	3.28	4.70	4.94	79	110	160	148	210	220
GO HT LP	3.15												
GO HT MP revamp								532	517	489	466	436	462
GO HT HP	0.83												
GO HDA			1.60	5.64	10.84	18.19	23.09		102	351	651	1053	1315
SRU	0.60	0.15	0.14	0.20	0.21	0.24	0.23	93	90	113	116	132	126
FGDS	1.01												
Bitumen	5.95												
Lubs	1.18												
Hydrogen manuf (as hydrogen) (1)	*25*	*92*	*115*	*140*	*170*	*197*	*204*	161	200	241	291	334	345
Hydrogen scavenging (1)	*7*	*59*	*60*	*59*	*59*	*59*	*59*	78	80	78	79	79	79
POX + GT													
IGCC	0.54												
POX + hydrogen	0.08												
POX + methanol	0.39												
Steam cracker	15.89	2.00	1.95	2.45	3.27	3.73	4.00	341	329	445	660	785	853
hydrodealkylation	0.27												
Total								**2572**	**3120**	**3372**	**3853**	**4533**	**4582**

(1) Capacities expressed in kt/a

France

		Used capacity Mt/a						Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
FRA: France													
CDU	94.59	1.30	5.62	4.55	4.12	1.27	3.20	8	40	32	28	8	21
HVU	41.62												
Visbreaker	9.10												
Del coker													
C4 deasphalting													
FCC	19.02												
Cracked gasoline splitter	1.90	4.39	4.11	4.18	4.22	4.29	4.11	43	41	42	42	43	41
HCU recycle													
HCU once-through	0.94	0.49						82					
Cat feed HT	5.60												
LR HDS													
Resid hydroconversion													
Naph HT	20.04												
Cracked gasoline HT	0.19	4.09	4.44	4.34	4.17	4.15	4.05	305	329	321	310	309	302
Cracked gasoline sweetening		0.18	0.12	0.12	0.12	0.12	0.12	12	8	8	8	8	8
Cat reforming revamp								131	135	132	132	131	130
Cat reforming (LP)				0.14	0.34	0.15	0.28			24	56	25	46
Reformate splitter	6.61												
Light reformate splitter	1.10												
Aromatics Extraction	0.02	0.09	0.07	0.09	0.11	0.10	0.08	8	6	7	9	8	7
Alkylation	1.25												
Isomerisation once-through													
Isomerisation recycle	3.30												
MTBE	0.47												
TAME	0.12												
Butamer	0.18												
PP splitter	0.64	0.12	0.12	0.13	0.13	0.13	0.09	26	26	27	27	27	18
Kero HT		2.44	4.03	3.57	4.62	3.88	5.23	110	178	159	203	172	227
GO HT LP	2.95												
GO HT MP revamp								305	316	277	239	179	180
GO HT HP													
GO HDA				3.29	6.07	11.99	14.25			206	370	698	819
SRU	0.28	0.05	0.07	0.06	0.06	0.04	0.05	23	35	32	34	17	22
FGDS		0.52	0.57	0.52	0.53	0.53	0.58	109	119	109	110	111	120
Bitumen	3.42	0.36	0.36	0.36	0.36	0.36	0.36	15	15	15	15	15	15
Lubs	1.76												
Hydrogen manuf (as hydrogen) [(1)]		*41*	*40*	*57*	*74*	*97*	*104*	72	70	98	127	165	176
Hydrogen scavenging [(1)]	*5*	*29*	*29*	*29*	*30*	*29*	*30*	39	38	39	40	39	40
POX + GT													
IGCC													
POX + hydrogen													
POX + methanol													
Steam cracker	9.55	1.97	2.17	2.11	2.09	2.16	2.18	400	455	437	433	450	455
hydrodealkylation	0.16												
Total								**1687**	**1810**	**1963**	**2182**	**2403**	**2628**

[(1)] Capacities expressed in kt/a

Iberia

	Used capacity Mt/a							Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
IBE: Iberia													
CDU	78.74	5.10	5.44	5.88	6.11	6.23	6.31	37	40	44	46	47	48
HVU	27.84	1.28	1.72	1.74	1.81	1.64	1.65	13	19	19	20	18	18
Visbreaker	9.91												
Del coker	2.42												
C4 deasphalting													
FCC	11.66												
Cracked gasoline splitter		4.02	4.05	3.99	4.05	4.05	4.05	39	39	38	39	39	39
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	3.24	3.27	2.99	3.07	3.10	3.13	236	238	219	224	226	228
Cracked gasoline sweetening		0.08	0.09			0.02	0.02	5	6			1	1
Cat reforming revamp								2	2	9	5	2	2
Cat reforming (LP)	1.48		0.10	0.15	0.36	0.37	0.32		9	15	47	49	40
Reformate splitter	4.82												
Light reformate splitter	0.86	0.09	0.13	0.18	0.21	0.12	0.05	3	4	5	6	4	2
Aromatics Extraction	0.97	0.51	0.51	0.54	0.54	0.47	0.49	36	36	38	38	33	34
Alkylation	0.85		0.01	0.01	0.01				1	1	1		
Isomerisation once-through	0.21												
Isomerisation recycle	0.59												
MTBE	0.31	0.01	0.01	0.01	0.01	0.01	0.01	3	3	3	3	3	3
TAME													
Butamer													
PP splitter	0.44	0.04	0.04	0.04	0.04	0.04	0.04	8	8	8	8	8	8
Kero HT		5.78	5.73	5.23	5.29	4.98	4.97	248	246	226	228	216	215
GO HT LP	3.68												
GO HT MP revamp								318	328	363	280	231	234
GO HT HP													
GO HDA				1.93	7.94	15.44	19.16			122	473	877	1071
SRU	0.38												
FGDS		0.24	0.26	0.27	0.24	0.20	0.18	51	54	57	51	42	37
Bitumen	2.67	0.03	0.03	0.03	0.03	0.03	0.03	1	1	1	1	1	1
Lubs	0.62												
Hydrogen manuf (as hydrogen) (1)	*26*	*32*	*33*	*41*	*73*	*103*	*119*	57	58	73	126	177	202
Hydrogen scavenging (1)	*4*	*31*	*31*	*32*	*32*	*32*	*32*	41	41	43	43	43	43
POX + GT													
IGCC													
POX + hydrogen													
POX + methanol													
Steam cracker	5.04	0.98	1.00	1.02	1.00	1.00	1.00	195	199	204	199	198	199
hydrodealkylation	0.09												
Total								**1292**	**1332**	**1487**	**1837**	**2213**	**2425**

(1) Capacities expressed in kt/a

Italy & Greece

		Used capacity Mt/a						Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
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	4.78	4.63	4.64	4.55	4.80	4.93	46	45	45	44	46	47
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	2.83	3.05	2.40	2.20	2.91	3.33	209	225	179	164	215	244
Cracked gasoline sweetening		0.73	1.33	1.07	1.07	1.22	0.37	46	80	66	66	74	24
Cat reforming revamp								0	2				
Cat reforming (LP)	4.72	1.86	1.42	1.99	2.08	1.91	1.96	259	195	278	290	266	273
Reformate splitter	8.39												
Light reformate splitter	1.78												
Aromatics Extraction	0.65	0.14	0.08	0.16	0.21	0.23	0.24	8	4	10	15	16	17
Alkylation	1.58												
Isomerisation once-through	1.02												
Isomerisation recycle	3.13												
MTBE	0.47	0.02	0.01			0.01	0.04	6	2			3	13
TAME	0.32												
Butamer	0.09												
PP splitter	0.55	0.15	0.14	0.14	0.14	0.16	0.19	26	23	23	23	27	34
Kero HT		10.13	9.64	10.41	11.97	9.93	7.11	435	416	446	508	427	313
GO HT LP	5.41												
GO HT MP revamp								530	478	461	355	377	479
GO HT HP													
GO HDA				0.79	7.93	18.09	23.97			51	490	1060	1377
SRU	0.69	0.13	0.14	0.10	0.09	0.14	0.14	90	92	63	57	92	92
FGDS	0.08	0.79	0.76	0.75	0.74	0.77	0.82	167	160	160	157	164	174
Bitumen	2.88	0.08	0.08	0.08	0.08	0.08	0.08	3	3	3	3	3	3
Lubs	1.62												
Hydrogen manuf (as hydrogen) (1)	*19*	*92*	*91*	*85*	*126*	*179*	*209*	160	158	148	216	305	354
Hydrogen scavenging (1)	*19*	*37*	*34*	*36*	*37*	*36*	*37*	51	47	50	50	49	51
POX + GT													
IGCC	1.47	0.88	0.88	0.90	0.88	0.94	0.91	668	668	681	673	714	694
POX + hydrogen	0.04												
POX + methanol													
Steam cracker	6.47	4.14	4.13	3.32	2.46	1.88	1.64	945	944	760	558	417	352
hydrodealkylation	0.11												
Total								**3649**	**3540**	**3423**	**3668**	**4255**	**4542**

(1) Capacities expressed in kt/a

Eastern Europe

	Used capacity Mt/a							Capex M€					
		Reference						Reference					
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**	**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5	11.0	4.0	3.0	2.0	1.0	0.5
EEU: Eastern Europe													
CDU	58.72												
HVU	25.73												
Visbreaker	2.64												
Del coker													
C4 deasphalting													
FCC	5.97												
Cracked gasoline splitter	0.59	2.84	2.76	2.76	2.77	2.72	2.96	27	26	26	26	26	28
HCU recycle													
HCU once-through	4.81	0.32	0.02		0.42	0.50	0.13	33	1		45	56	12
Cat feed HT	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
LR HDS													
Resid hydroconversion													
Naph HT	7.66												
Cracked gasoline HT		1.30	1.30	1.30	1.25	1.17	1.58	97	97	97	93	88	117
Cracked gasoline sweetening		0.94	0.94	0.93	0.95	0.96	0.86	55	55	55	55	56	51
Cat reforming revamp								121	117	117	119	120	115
Cat reforming (LP)	1.62	0.31	0.35	0.35	0.28	0.26	0.37	38	45	45	34	30	49
Reformate splitter	3.10	2.02	2.23	2.23	1.96	2.15	2.17	42	46	46	41	45	45
Light reformate splitter		0.31	0.37	0.36	0.32	0.33	0.29	8	10	10	9	9	8
Aromatics Extraction													
Alkylation	0.33	0.08	0.09	0.09	0.08	0.08	0.17	29	30	30	28	29	62
Isomerisation once-through	0.10	0.60	0.58	0.58	0.58	0.61	0.62	92	89	89	89	93	94
Isomerisation recycle	1.19	0.47	0.59	0.58	0.52	0.49	0.50	97	126	125	109	102	104
MTBE	0.15	0.01	0.01	0.01	0.01	0.01	0.02	2	3	3	2	1	6
TAME		0.70	0.69	0.69	0.70	0.72	0.62	109	108	108	110	113	97
Butamer													
PP splitter	0.22	0.01	0.02	0.02	0.01	0.01		2	2	2	2	1	
Kero HT		2.36	2.34	2.47	3.09	2.63	2.47	106	105	111	137	118	111
GO HT LP	3.12												
GO HT MP revamp								177	175	175	177	188	188
GO HT HP													
GO HDA					1.47	3.83	6.27				93	237	377
SRU	0.17	0.12	0.11	0.11	0.12	0.12	0.12	49	47	46	50	51	53
FGDS													
Bitumen	2.94												
Lubs	0.87												
Hydrogen manuf (as hydrogen) (1)	*23*	*21*	*17*	*17*	*30*	*45*	*49*	38	32	32	54	79	87
Hydrogen scavenging (1)	*8*	*15*	*15*	*15*	*14*	*14*	*15*	20	20	20	20	20	20
POX + GT													
IGCC		1.13	1.13	1.13	1.12	1.12	1.14	890	888	888	883	878	897
POX + hydrogen													
POX + methanol													
Steam cracker	3.43	0.57	0.52	0.52	0.58	0.63	0.62	106	94	95	109	121	120
hydrodealkylation	0.06												
Total								**2137**	**2114**	**2119**	**2285**	**2461**	**2641**

(1) Capacities expressed in kt/a

APPENDIX 4 ROAD DIESEL QUALITY

(Total and per region for each case)

		2010					
		Reference	Alternatives				
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5
Total							
Production	*Mt/a*	*182.5*	*182.4*	*182.1*	*181.8*	*181.5*	*181.4*
Density		0.831	0.831	0.826	0.823	0.821	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	28.7	27.4	23.8	19.2	13.9	11.1
Cloud pt	°C	-8.3	-8.4	-8.6	-6.4	-6.0	-6.0
CN Ind		50.3	50.5	50.9	50.3	51.0	51.8
Polyarom	% m/m	4.2	3.9	3.0	2.0	1.0	0.5
LHV	GJ/t	43.4	43.4	43.5	43.6	43.7	43.7
SCA							
Production	*Mt/a*	*11.0*	*11.0*	*11.0*	*10.9*	*10.9*	*10.9*
Density		0.822	0.821	0.821	0.820	0.820	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	25.5	25.5	24.6	20.6	15.0	12.0
Cloud pt	°C	-11.4	-11.5	-13.6	-7.5	-7.5	-7.5
CN Ind		49.0	49.0	49.0	49.0	49.0	50.6
Polyarom	% m/m	3.2	3.2	3.0	2.0	1.0	0.5
LHV	GJ/t	43.5	43.6	43.5	43.6	43.7	43.7
UKI							
Production	*Mt/a*	*23.3*	*23.3*	*23.3*	*23.2*	*23.2*	*23.2*
Density		0.838	0.834	0.832	0.827	0.823	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	30.3	26.6	22.8	18.2	13.7	10.9
Cloud pt	°C	-5.2	-5.0	-5.0	-5.0	-5.0	-5.3
CN Ind		52.1	52.2	52.2	51.7	52.5	53.1
Polyarom	% m/m	4.7	4.0	3.0	2.0	1.0	0.5
LHV	GJ/t	43.4	43.4	43.5	43.6	43.6	43.7
BEN							
Production	*Mt/a*	*22.6*	*22.6*	*22.5*	*22.5*	*22.5*	*22.5*
Density		0.825	0.826	0.821	0.820	0.820	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	26.0	26.1	23.2	18.7	13.3	10.6
Cloud pt	°C	-6.5	-6.5	-6.7	-5.0	-5.0	-5.0
CN Ind		52.0	51.8	53.0	52.8	52.6	52.4
Polyarom	% m/m	3.7	3.7	3.0	2.0	1.0	0.5
LHV	GJ/t	43.6	43.6	43.6	43.7	43.7	43.7
MEU							
Production	*Mt/a*	*33.3*	*33.2*	*33.2*	*33.1*	*33.0*	*33.0*
Density		0.840	0.839	0.834	0.828	0.821	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	30.6	27.7	23.8	18.2	13.6	11.0
Cloud pt	°C	-5.6	-5.3	-5.3	-5.3	-5.3	-5.3
CN Ind		49.6	49.6	49.8	50.1	50.8	51.3
Polyarom	% m/m	4.8	4.0	3.0	2.0	1.0	0.5
LHV	GJ/t	43.3	43.3	43.4	43.6	43.7	43.7

See notes on cetane index in **Section 2.3**

		2010					
		Reference	Alternatives				
PAH specification		**11.0**	**6.0**	**4.5**	**3.5**	**2.0**	**1.0**
PAH limit for model		11.0	4.0	3.0	2.0	1.0	0.5
FRA							
Production	*Mt/a*	*20.9*	*20.9*	*20.8*	*20.8*	*20.8*	*20.8*
Density		0.837	0.831	0.829	0.824	0.823	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	32.4	28.7	24.0	20.6	15.4	12.7
Cloud pt	°C	-9.1	-9.0	-4.6	-4.6	-4.9	-5.5
CN Ind		49.0	50.6	50.9	49.0	49.9	50.0
Polyarom	% m/m	4.7	4.0	3.0	2.0	1.0	0.5
LHV	GJ/t	43.3	43.4	43.5	43.5	43.6	43.6
IBE							
Production	*Mt/a*	*27.0*	*27.0*	*27.0*	*26.9*	*26.9*	*26.9*
Density		0.831	0.831	0.827	0.823	0.820	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	29.4	28.4	24.6	19.5	13.5	10.8
Cloud pt	°C	-8.4	-8.5	-9.6	-7.7	-7.1	-7.2
CN Ind		49.5	49.9	50.4	50.5	52.0	51.8
Polyarom	% m/m	4.2	4.0	3.0	2.0	1.0	0.5
LHV	GJ/t	43.4	43.4	43.5	43.6	43.7	43.7
ITG							
Production	*Mt/a*	*34.4*	*34.4*	*34.4*	*34.4*	*34.3*	*34.3*
Density		0.822	0.825	0.820	0.820	0.820	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	26.4	27.7	24.0	19.6	13.5	10.7
Cloud pt	°C	-12.6	-13.1	-14.3	-8.9	-7.2	-6.4
CN Ind		50.3	49.9	50.7	49.0	50.3	51.4
Polyarom	% m/m	3.5	3.8	3.0	2.0	1.0	0.5
LHV	GJ/t	43.6	43.5	43.6	43.6	43.7	43.7
EEU							
Production	*Mt/a*	*8.8*	*8.7*	*8.7*	*8.7*	*8.7*	*8.7*
Density		0.834	0.831	0.820	0.820	0.820	0.820
Sulphur	ppm	7	7	7	7	7	7
Aromatics	% m/m	27.8	26.9	23.3	18.7	14.0	10.2
Cloud pt	°C	-7.3	-7.7	-11.5	-5.0	-5.0	-5.0
CN Ind		51.1	51.3	51.5	49.9	49.6	55.2
Polyarom	% m/m	4.3	4.0	3.0	2.0	1.0	0.5
LHV	GJ/t	43.4	43.5	43.6	43.7	43.7	43.7