Techno-economic analysis of the impact of the reduction of sulphur content of residual marine fuels in Europe

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ABSTRACT

Annex VI of the IMO's MARPOL convention is coming into force in 2006 for the Baltic Sea and 2007 for the North Sea, imposing a 1.5% m/m sulphur cap on residual marine fuel (RMF) burned in these areas. At the same time EU Directive 2005/33/EC will further extend the 1.5% cap to ferries operating from and to an EU port. These provisions are subject to further review in the near future, opening the possibility of further sulphur reductions. In this context CONCAWE undertook a study to evaluate the impact of these measures on EU refineries and the consequences for RMF cost. The study concludes that, faced with the prospect of desulphurising residual streams, refiners would have a clear incentive for full conversion. This would push the price of low sulphur RMF well beyond the costs related to desulphurisation, close to the price of gasoil.

KEYWORDS

Residual marine fuels, Bunker fuels, SECA, Sulphur, Desulphurisation, Conversion

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SUMMARY

Two major pieces of legislation affecting the sulphur content of marine fuels will come into force in the coming two years. The Baltic and North Sea will become "Sulphur Emissions Control Areas" (SECA) under MARPOL Annex VI whereby the emissions of ships sailing in these areas will be limited to a level consistent with a maximum fuel sulphur content of 1.5% m/m. A revision process of that legislation was initiated by the IMO's Marine Environment Protection Committee in July 2005. In addition the EU has adopted Directive 2005/33/EC[1] which extends the 1.5% m/m sulphur limit to all ferries operating from and to an EU port. The Directive includes a review clause whereby the possibility can be envisaged of extension of the sulphur limit to all EU waters and its further reduction (levels of 0.5% m/m have been mentioned).

In this context CONCAWE undertook this study with the objectives to clarify the options open to European refiners facing these new constraints, including possible future ones and to analyse the impact of refiners' choices on the residual marine fuel (RMF) market in terms of availability and prices.

When faced with an additional constraint, a refiner will re-evaluate its entire operation to try and find the new economic optimum. Focussing on RMF sulphur reduction, the options would in principle be as follows:

- Optimise residue streams segregation and residual fuel blending,
- Process more low sulphur crude,
- Desulphurise residues,
- Convert residual streams to distillate products,
- Export surplus high sulphur residual fuel.

Today residual fuels are produced without having to process the residues themselves resulting in a low cost, low price fuel. Limited quantities of low sulphur fuel oils can be prepared by selecting and segregating residues from low sulphur crudes and back-blending with lighter low sulphur components. Residue desulphurisation is technically feasible but is not a trivial matter. It is used to produce feedstocks for conversion units but has not commonly been applied to produce commercial fuels including RMF. The processes involved are complex, the plants costly and delicate to operate. Blended fuel stability and mutual compatibility can cause problems, especially with the heavier, higher sulphur residues. The processes apply technologies similar to hydroconversion (i.e. cracking to lighter material) but under somewhat milder conditions. Although several such processes are commercially proven they are regarded as state-of-the-art technologies particularly when it comes to treating heavy and high sulphur residues (e.g. from Middle Eastern crudes). There are a few residue desulphurisation plants in the world today however none of them is actually producing components for making LS RMF.

A significant reduction of the sulphur content of a large proportion of the residual fuels would therefore change their very nature. They would become manufactured products having to support complex and expensive processing equipment. As a

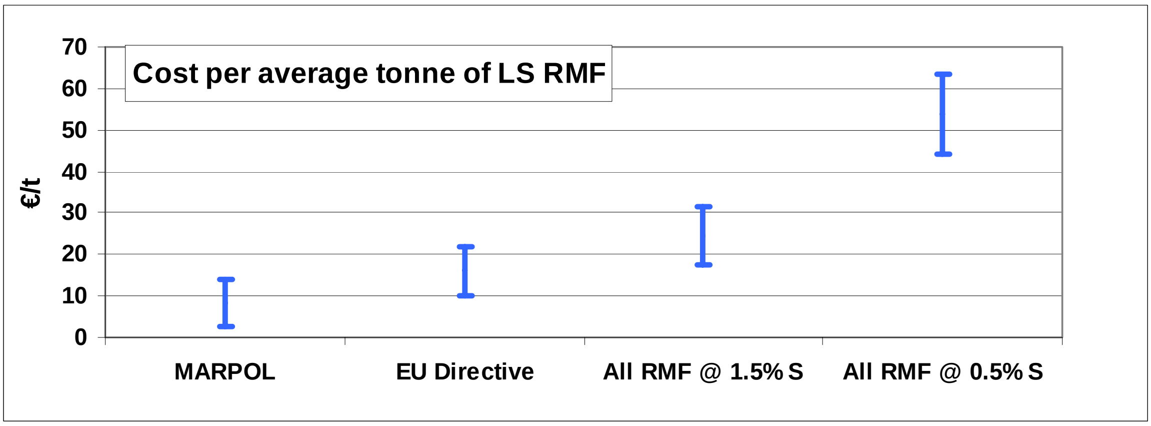
[1] Directive 2005/33/EC of the European Parliament and of the Council of 6 July 2005 amending Directive 1999/32/EC as regards the sulphur content of marine fuels

result their production would be in economic competition with other manufactured products such as distillates.

Starting from a pre-SECA "business-as-usual" case, the study considered two scenarios based on enacted legislation (MARPOL legislation alone, MARPOL + EU Directive) and two further prospective scenarios in which the sulphur content of all RMF sold in the EU would be limited to either 1.5 or 0.5% m/m. Demand figures were based on a 2015 forecast.

In a first part we estimated the cost to EU-27 (EU-25 + Norway and Switzerland) refineries of reducing RMF sulphur to the required level while meeting the RMF demand.

As already highlighted in studies by others, residue desulphurisation has a high cost. Meeting already enacted legislation will require investments of up to 2 G€ in EU-27 for an annualised cost in the order of 0.5 G€/a. Reducing the sulphur content of all RMF sold in Europe to 0.5% m/m would require an investment of between 7 and 13 G€ for an annualised cost 2.2 to 3.2 G€/a. The corresponding ranges of cost per tonne of low sulphur (LS) RMF are shown in the figure below.



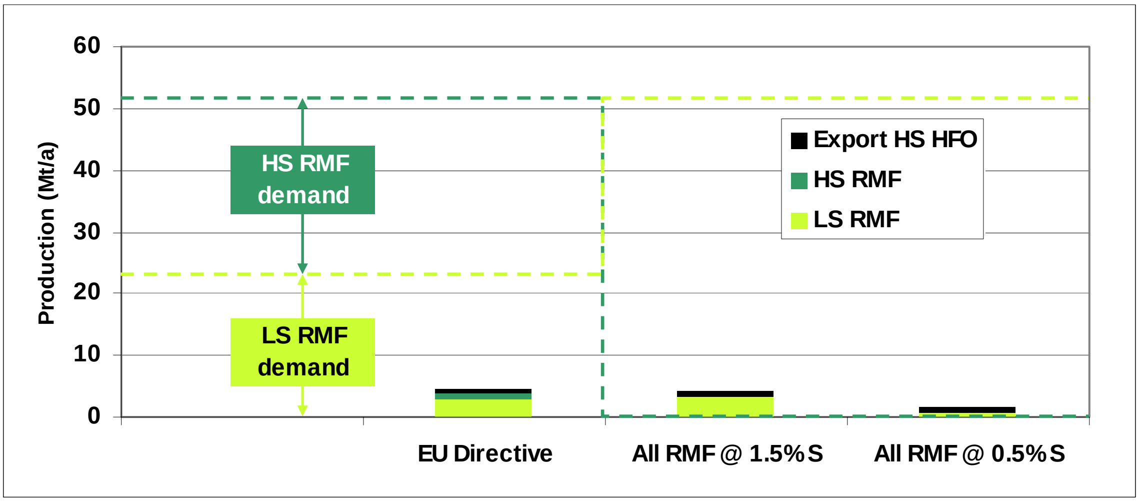
The average cost per tonne of LS RMF would be between 10 and 25 €/t to meet enacted legislation increasing to 45 to 65 €/t in the 0.5% sulphur case.

These costs, however, do no reflect the impact of the RMF sulphur limits on its likely market price. From an economic point of view desulphurisation relies on the differential between low and high sulphur residual fuels which is only established on the basis of legislated sulphur limits. Conversion also requires complex and costly plants but delivers distillate products that are inherently more valuable than residues. Its economic prospects are therefore much better than desulphurisation.

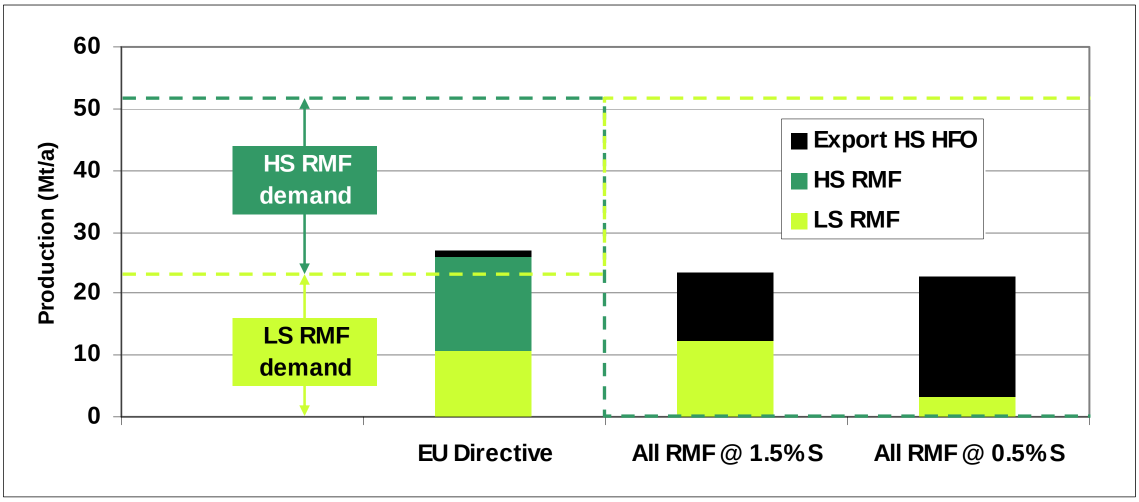
In reality refiners will always have the choice to only supply the portion of the market which is economically attractive. In a second part we therefore considered the relative merits of residue desulphurisation (for LS RMF production), conversion to lighter products or export outside the EU. In addition to the reference price scenario (38-40 $/bbl) we also used a low price set (around 25 $/bbl) in order to test the sensitivity of the results to this essential economic driver.

As shown in the figures below, our key finding is that, under both price scenarios conversion or export would be more attractive than desulphurisation.

Reference price scenario (38-40 $/bbl)



Low price scenario (25 $/bbl)



The LS RMF price increase required to make desulphurisation attractive would be very high. In order to re-establish the full LS RMF production in our reference price scenario, differentials between HS and LS RMF in the order of 90 €/t would be required in the EU Directive case and up to 140 €/t in the 0.5% overall sulphur limit case. This would bring the price of LS RMF close to that of heating oil, which would then make LS RMF and unattractive customer choice.

1. CONTEXT AND BACKGROUND

Residual fuel is a commodity used by sea-going vessels the world over. The quality specifications of residual marine or "bunker" fuels (RMF), as defined in ISO 8217, result essentially of self-regulation of the industry and agreements between producers and consumers. Parameters such as carbon residue, density and stability are essential for the safe operation of ships.

The sulphur content of marine fuels is, however, regulated on a worldwide basis though the International Maritime Organisation (IMO). An agreement under the International Convention for the Prevention of Pollution from Ships (MARPOL), known as MARPOL Annex VI, has introduced a global RMF sulphur content cap of 4.5% m/m as per May 2005. It has also introduced the concept of Sulphur Emission Control Areas (SECA) which are special sea areas where ship sulphur emissions are consistent with a fuel having a maximum sulphur content of 1.5% m/m. The Baltic and North Sea have been designated as SECAs. Following its ratification in 2005, MARPOL Annex VI will come into force as of May 2006 for the Baltic Sea and November 2007 for the North Sea. A revision process of that legislation was initiated by the IMO’s Marine Environment Protection Committee in July 2005.

In addition, the EU has adopted Directive 2005/33/EC[1] (further referred to as "the Directive") which extends the 1.5% m/m sulphur limit to all ferries operating from and to an EU port and will also come into effect in August 2006. The Directive includes a review clause whereby the possibility can be envisaged of extension of the sulphur limit to all EU waters and its further reduction (levels of 0.5% m/m have been mentioned).

It has to be noted that the obligation under the Directive could also be met by appropriate reduction of the ship stack emissions. This can be achieved by sea water scrubbers, a number of which have been developed to full scale demonstration stage. This study examines the fuel desulphurisation option.

In this context CONCAWE undertook this study with the objectives to:

Clarify the options open to European refiners facing these new constraints, including possible future ones,

Analyse the impact of refiners' choices on the RMF market in terms of availability and prices.

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[1] Directive 2005/33/EC of the European Parliament and of the Council of 6 July 2005 amending Directive 1999/32/EC as regards the sulphur content of marine fuels

2. REFINERY RESIDUAL STREAMS

The so-called "residual" refinery streams are heavy materials left over after distilling off the lighter portion of crude oil or, more generally in modern refineries, after converting part of the heavy virgin material into lighter products. These heavy residues are partly used for bitumen manufacture but the bulk is sold as fuel for either inland applications (mostly power generation and cement manufacture) or as marine fuels. Historically the production of such heavy residue has proportionally decreased under the combined pressure of increased demand for "distillates" and dwindling demand for heavy material. The marine bunker market has, however, provided a steady outlet for these products.

The development of the marine bunker fuel market started in earnest after WWII and has been a win-win proposition for the shipping and the refining industries. Shipping companies have enjoyed cheap fuel while refineries found an outlet for streams that were difficult to valorise.

Residual fuels are of course sold against a specification but this can generally be achieved by back-blending with lighter components. Limited quantities of low sulphur fuel oils can be prepared by selecting and segregating residues from low sulphur crudes. Residual fuels are therefore generally produced without having to process the residues themselves and therefore fairly cheaply.

3. REFINERY BUSINESS OPTIONS IN LOW SULPHUR RMF SCENARIOS

A refinery processes crude oil to produce a variety of products, all of which have to find an outlet either as a marketable product or as internal fuel for the refinery (although this option is clearly limited). The options open to a given refiner to "balance the books" depend on many factors be it physical limitations (process plants capacity performance and flexibility, location, import/export facilities) or economic constraints (access to advantageous crudes, ability to produce a margin).

When faced with an additional constraint, a refinery will re-evaluate its entire operation to try and find the new economic optimum. Focussing on RMF sulphur reduction, the options would in principle be as follows.

Optimise residue streams segregation and residual fuel blending

This is a relatively soft option for the refiner although it may require minor investments to make segregation possible. Clearly, however, the scope is limited to the volumes of low sulphur residual streams physically available and also by a number of practical considerations that would make segregation impossible. The current demand to cover the requirement of the Directive could partly be met through this mechanism.

Process more low sulphur crude

This option is of course in principle open to individual refiners. It must, however, be realised that the trend is for crude oil worldwide to become heavier and more sulphurous. Globally for Europe, it has been estimated that the current low/high sulphur ratio (about 45/55) can at best be maintain for the next 10-15 years but could not realistically be increased. From a European point of view this option is therefore not available.

Desulphurise residues

On paper, the simplest way to reduce sulphur in RMF is to desulphurise key residual components. Residue desulphurisation is technically feasible but is no trivial matter. It is used to produce feedstocks for conversion units but has not commonly been applied to produce commercial fuels including RMF. It requires heavy processing, essentially high pressure/high temperature hydrotreatment. The processes involved are complex, the plants costly and delicate to operate. Blended fuel stability and mutual compatibility can cause problems, especially with the heavier, higher sulphur residues. The processes are similar in nature from hydroconversion (i.e. cracking to lighter material). They apply similar technologies but under somewhat milder conditions. Although several such processes are commercially proven they are regarded as state-of-the-art technologies particularly when it comes to treating heavy and high sulphur residues (e.g. from Middle Eastern crudes). There are a few residue desulphurisation plants in the world today however none of them is actually producing components for making LS RMF.

A significant reduction of the sulphur content of a large proportion of the residual fuels would therefore change their very nature. They would become manufactured products having to support complex and expensive processing equipment. As a result their production would be in economic competition with other manufactured products such as distillates. As a result, refiners would inevitably consider alternatives.

Convert residual streams to distillate products

As the market has gradually moved towards more distillates and less residual fuels (a "whiter demand barrel") while the average crude oil barrel on offer was slowly becoming heavier, the refining industry has adapted by installing "conversion" capacity i.e. plants that can turn residues into distillates such as diesel fuel, kerosenes or gasolines. Such plants are in fact very similar to those required to desulphurise residues, the difference being more in the degree of severity applied than in the process principles used. Conversion is likely to be more expensive than desulphurisation but not by a large margin. As a result partial or full conversion will always be an option when desulphurisation is considered.

The economics of desulphurisation would rely on an expected price differential between low and high sulphur RMF. The magnitude and evolution with time of such a differential would be crucially dependent on the supply/demand balance of low sulphur material and the evolution and application of the legislation that created the demand in the first place. Compared with these uncertainties, conversion relies on the continued prospect of sustained distillate growth and decreasing demand for residues, offering a more reliable basis on which to decide what would in any case be major investments.

It must be noted that conversion is not the only technological option available to the refiner to deal with residual streams. Residue gasification for heat and power production offers a further alternative which may be attractive under certain circumstances and would also be in competition with the desulphurisation option. Although our model is able to represent such processes we have not included this option in our study as consideration of the relative economics of conversion and gasification would have required discussion of relative electricity and oil prices that would be beyond our scope.

Export surplus high sulphur residual fuel

The worldwide RMF market is set to grow steadily and, with no immediate prospects of additional sulphur restrictions outside Europe and limited parts of the US and Japanese coastal areas, export is likely to remain an option even though this would bring a reduced income to European refiners. There may also be opportunities for export of high sulphur heavy fuel oil (HS HFO) for other uses. This option might be considered where funding for the large desulphurisation or conversion investments is not available.

4. METHODOLOGY AND STUDY CASES

4.1. 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. The model is carbon balanced and can therefore also estimate the impact of changes in terms of CO_2 emissions from both refinery sites and modified fuels when used.

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 was the year 2005. The plant capacities required to meet the base case demand and qualities (which should of course be close to the actual ones) were then frozen.

The future year selected for crude supply, product demand and quality forecasts was 2015. A 2015 reference case was established, in which only already agreed and/or legislated changes are included. As such the reference case includes full implementation of the Directive. The crude diet was not considered as a relevant parameter inasmuch as an increase in the overall supply of low sulphur crudes is not a credible scenario. The crude diet was therefore fixed in all cases only one crude (Heavy Middle East) being allowed to vary to balance the requirements (e.g. for energy). Product demands for a certain year were mostly fixed. Some cases included variable RMF demands to show the effects of economics on the production level. Whenever appropriate the model was allowed, at a cost, to increase the capacity of existing units as well as use new units to meet the constraints.

Alternative cases were run from the base case with specific additional constraints, thereby providing alternative paths to the future compared to the reference case. This approach assumes that all alternatives would be considered within the same timeframe. If this were not the case, there could 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. Wherever appropriate we have flagged whether or not we have taken the regret investment into consideration and for what reasons.

The geographic scope for the model was EU-25 + Norway and Switzerland ("EU-27") split into 8 regions. Each region is represented by a composite refinery having, for each process unit, the combined capacity of all refineries in the region (Table 1). Exchanges of key components and finished products between regions are allowed at a cost.

Table 1 The 8-regions of the CONCAWE EU refining model

Region	**Code**	**Countries**	**Total crude distillation capacity** Mt/a
Baltic	BAL	Denmark, Finland, Norway, Sweden, Estonia, Latvia, Lithuania	55
Benelux	BNX	Belgium, Netherlands, Luxembourg	102
Germany	GER	Germany	111
Central Europe	CEU	Austria, Switzerland, Czech, Hungary, Poland, Slovakia	51
UK & Ireland	UKI	United Kingdom, Ireland	73
France	FRA	France	98
Iberia	IBE	Spain, Portugal	78
Mediterranean	MED	Italy, Greece, Slovenia, Malta, Cyprus	109

4.2. STUDY CASES

Starting from a base case representing the current situation (2005) a number of scenarios were analysed based on the projected 2015 demand pattern.

Complying with sulphur limits while meeting demand
In the first part of the analysis we considered that EU refineries have to meet the demand for all products including RMF. The demand figures were therefore fixed as well as the crude slate. The model was allowed to build additional plant capacity to meet the additional RMF sulphur constraint.

The reference case assumed the pre 2005 legislation i.e. no restrictions on RMF beyond the general 4.5 % m/m sulphur cap. Four alternative cases were considered with increasingly severe restrictions

- MARPOL Annex VI (SECAs)
- EU Directive 2005/33/EC (SECAs + Ferries)
- All RMF at 1.5% m/m
- All RMF at 0.5% m/m

Exercising refiner's options: full flexibility scenario
In reality, individual refiners always have the choice to supply the demand up to a point, generally representing their economic optimum. As explained in section 3, conversion of residues and export of HS HFO are both realistic alternative options. We have represented these options by leaving the model free to meet any portion of the low sulphur RMF demand while providing an optional high sulphur HFO export demand and the option to invest in new plants for either desulphurisation or conversion of residues.

In this case the main drivers for the refiner will be the price differentials between

- HS HFO and distillates (represented by the price of heating oil) i.e. the incentive to convert residues.
- HS and LS RMF i.e. the incentive for residue desulphurisation

The former differential is determined by the price scenario used. To analyse the impact of the latter we have performed runs at increasing LS RMF price (starting from the basic scenario value and with heating oil price as a backstop).

Exercising refiner's options: minimum investment scenario
Finally we considered a scenario where refiners would be restricted to minimum investment with the choice to make all or portion of the LS RMF demand (through investment) while exporting the balance of the available residual streams (in the form of HS RMF). In this case the economic driver is of course the price differential between LS and HS RMF which we have accordingly varied in the same range in the previous scenario.

All scenarios were simulated with the high and low price scenarios defined above.

The following table summarises the study cases and their features.

Table 2 Study cases

Scenario	Year	S in RMF (1)	RMF Demand	RMF export	LS RMF price	Investment
Base	2005	A	Fixed	No	Fixed	NA
Reference	2015	A	Fixed	No	Fixed	NA
Complying with enacted legislation while meeting demand	2005	B, C	Fixed for both LS and HS grades	No	Fixed	Open
Making LS RMF	2015	C, D, E	Fixed for both LS and HS grades	No	Fixed	Open
Exercising refiner's options	2015	C, D, E		Open	(2)	Open
Full-flexibility			Free for both grades with maximum as per reference			
Minimum investment			Total fixed, grade proportion free			

(1) RMF sulphur specification scenarios
A: Current (<4.5%)
B: MARPOL (<1.5% in SECAs)
C: EU Directive (<1.5% in SECAs and for EU ferries)
D: <1.5% for whole demand
E: <0.5% for whole demand
(2) LS RMF price gradually increased from reference to re-establish LS RMF production level

Comparison of cases

Each study case started with the 2005 base case in terms of refinery configurations and available plant capacities. The demand pattern was adjusted to 2015 and the appropriate RMF sulphur limits were introduced in each case.

Comparing each case with the 2005 base case describes a direct path from "now" to a certain future scenario. This path assumes that all adaptations and investments are geared to that future from the outset and therefore offers the lowest cost. It implies that the future constraints are already known and acted upon today.

Another extreme is to consider that refineries continue to plan with current specifications to 2015 (reference case) and only then put in place additional investments to meet the additional sulphur constraints. This of course leads to a sub-optimum situation and to regret investments as part of the hardware required to reach the reference case is different from what is required for other cases.

As always, reality will be between these two extremes which we have used to represent the range of potential costs.

4.3. PRICE SCENARIOS, SUPPLY/DEMAND FORECASTS AND CALL ON REFINERIES

Supply/demand and call on refineries
The base case represents the situation today (2005), both in terms of demand and RMF specification. It does not therefore include the impact of implementation of the new marine fuel sulphur restrictions. The demand scenario for 2015 was consistent with a recent industry study by Wood Mackenzie. The reference case, against which other cases are compared, represents a notional scenario with that 2015 demand set and RMF specification unchanged from 2005.

Although the EU market is essentially supplied by EU refineries, there are significant import/export streams that need to be taken into account to arrive at a realistic estimate of the call on refineries. The 2005 import/export figures were best estimates based on available statistics. For the 2015 reference case most figures were left unchanged with the notable exceptions of the elimination of the naphtha and of the residual fuel oil imports (lower overall demand of gasoline +naphtha and of residual fuels).

Table 3 EU-27 demand, import/export and call on refineries
2005 base case and 2015 reference case

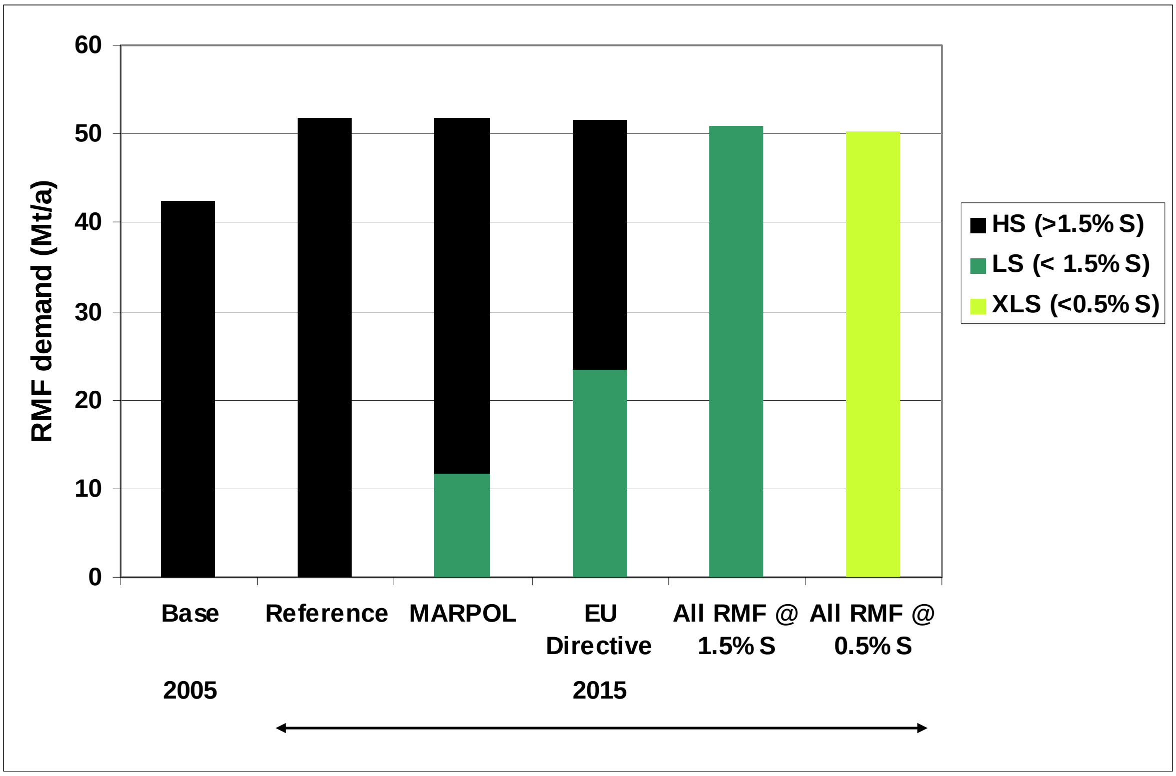
Product (Mt/a)	2005 base case			2015 reference case		
	Demand	**Import (-)/ Export (+)**	**Call on refineries**	**Demand**	**Import (-)/ Export (+)**	**Call on refineries**
LPG	27	-6	21	27	-6	21
Chemical feed naphtha	49	-9	40	52		52
Olefins	40		40	47	-2	45
BTX	14		14	18		18
Gasolines	117	22	139	97	22	119
Jet fuel	55	-8	47	71	-8	63
Automotive gasoil (diesel fuel)	183	-10	173	237	-10	227
Industrial gasoil / Heating oil	98	-10	87	82	-10	71
Marine gasoil	13		13	15		15
Inland residual fuel oil			0			0
Low sulphur (<1% S)	48		48	36		36
High sulphur	3		3	3		3
Residual marine fuel oil						
Low sulphur (<1.5%)	(1)					
High sulphur	42	-10	32	52		52
Bitumen	20		20	22		22
Lub base oils	6		6	6		6

(1) A small amount of LS RMF is produced in Europe today as a result of e.g. national tax incentives. We have chosen to ignore this in order to show the whole impact of the legislation

Marine fuels represent a large market in Europe. RMF 2005 demand is estimated at around 42 Mt. It represents about 45% of the outlet of refineries for residues (the other half being used in inland applications). The European residual fuel balance has fluctuated over the years between net import and net export. In recent years (2003) Europe has been a net importer of about 10 Mt/a of residual fuels. In addition 12 Mt of distillate fuel are used in marine applications (including inland waterways).

By 2015 RMF demand is expected to increase to 52 Mt. With the implementation of the Directive demand for low sulphur grades will increase to nearly 23 Mt (***Figure 1***). With a sharp decrease of inland residual fuel it is expected that there will be no net imports by then, marine demand now representing some 55% of the total residual fuel outlet. Demand for marine distillate fuel is also expected to increase to about 15 Mt.

Figure 1 Evolution of EU-27 RMF demand per grade



Note: the total RMF demand in Mt/a contracts slightly as sulphur content decreases. This is the result of our modelling assumption whereby we consider that the demand for fuel components is in energy rather than mass terms. As fuels are desulphurised their specific heating value increases and less tons are required for the same energy content.

Crude supply

The total EU crude mix for 2005 was based on best estimates of actual figures and included some 45% low sulphur grades. The composition of the total EU crude supply was maintained approximately constant between 2005 and 2015. Changes in crude allocation between regions were allowed. The necessary flexibility to cope with changes in alternative scenario was provided in the form of heavy Middle East crude.

Table 4 EU-27 crude oil supply
2005 base case and 2015 reference case

Crude	Assay used	Base case 2005 Mt	Base case 2005 %	Reference case 2015 Mt	Reference case 2015 %
Low Sulphur Paraffinic	Brent	253	37%	268	36%
Low Sulphur Naphthenic	Forecados	59	9%	62	8%
Condensate	Algerian	2	0%	2	0%
Mid East, medium	Iranian light	143	21%	160	21%
Russian, medium	Urals	114	17%	127	17%
Mid East, heavy	Kuwait	107	16%	126	17%
Total Crude		678	100%	745	100%
Low Sulphur		314	46%	332	45%
High Sulphur		364	54%	412	55%

The full refinery material balance is shown in ***Appendix 1***, for the total of EU-27 as well as for each of the 8 regions considered.

Cost of capital and operating costs

We represented the cost of capital by applying a capital charge calculated as a fixed yearly percentage of capital investment. Our normal value is 15% which is the annual revenue that a company should produce, after operating costs and before tax, in order to achieve an Internal Rate of Return of 8%. We have used this figure in the fixed demand cases. In the variable demand cases we have applied a higher capital charge of 25% as a conservative measure to make investment less attractive and therefore favour no or low investment routes.

The operating costs included the cost of extra CO_2 emissions assuming a CO_2 market price of 20 €/t.

Price scenarios

Two price scenarios were used: The average of the year 2004 provided a scenario based on a oil barrel between 35 and 38 $ which can be construed as a medium-term scenario and which we considered as the reference. The year 2002 provided a low price alternative

Table 5 Price scenarios

	Price Scenario	
	Reference	Low
Based on year	2004	2002
Crude (FOB NWE)		$/t ($/bbl)
Low sulphur paraffinic	289 (38.1)	190 (25.1)
Low sulphur naphthenic	273 (38)	179 (24.9)
Russian medium	264 (36.4)	173 (23.8)
Middle East medium	253 (34.6)	177 (24.2)
Middle East heavy	244 (33.9)	173 (24)
Products (Cargoes FOB NWE)		$/t
Ethylene	784	489
Benzene	849	342
LPG	360	225
Naphtha	377	224
Premium Unleaded	392	239
Jet A-1	386	223
Road Diesel	359	213
Heating Oil	343	201
LS HFO 1%	163	134
HS HFO 3.5%	137	116
Key differentials		
HFO, per % S	*10*	*7*
IGO-HS HFO	*206*	*85*

Note: although prices are labelled in $ we assumed €/$ parity

These scenario prices were used to calculate market prices in each region based on the supply/demand balance in that region and notional transport costs from/to the main price-setting markets (Rotterdam in Northern Europe and Sicily in Southern Europe).

In the fixed demand cases the model was forced to resolve its constraints by investment in new plants. The impact of the general price scenarios on such cases was very limited. We have therefore only used the reference scenario in these cases.

In the variable demand cases, however, the model was largely driven by price differentials and the relative magnitude of operating margin and investment costs. The price level played therefore a key role and we have illustrated this by using both price scenarios.

5. RESULTS

5.1. COMPLYING WITH SULPHUR LIMITS WHILE MEETING THE DEMAND

Within the next few years, EU refineries will have to adapt to meet the changing RMF demand resulting from the entering into force of the new MARPOL Annex VI and the Directive. Beyond this we have considered two prospective scenarios where all RMF sold by EU refineries would carry a sulphur limit of 1.5% and 0.5% m/m respectively.

In this part of the study we assumed that refineries continue to supply the market demand which has been set as per our 2015 forecast. The increasing LS RMF market share had to be met by a combination of optimised component segregation and blending and of investment.

These runs were carried out under a single price scenario (reference) inasmuch as, when the model is compelled to produce the demand and when investment is the only mechanism allowed, the absolute price level has little influence on the result.

Figure 2 shows the range of capital investment required over and above the reference case, to meet the 2015 demand as the sulphur limits become more stringent. The low end of the range assumes no regret investment while the high end assumes that all investments made for the reference case and not used are lost.

Figure 3 shows the corresponding annualised costs, including a 15% capital charge as well as the full set of variable and fixed operating costs. ***Figure 4*** shows the cost per average tonne of LS RMF.

This data is also shown in tabular form in ***Appendix 2***.

Figure 2 Capital investment required for implementation of sulphur limits (2015 demand basis)

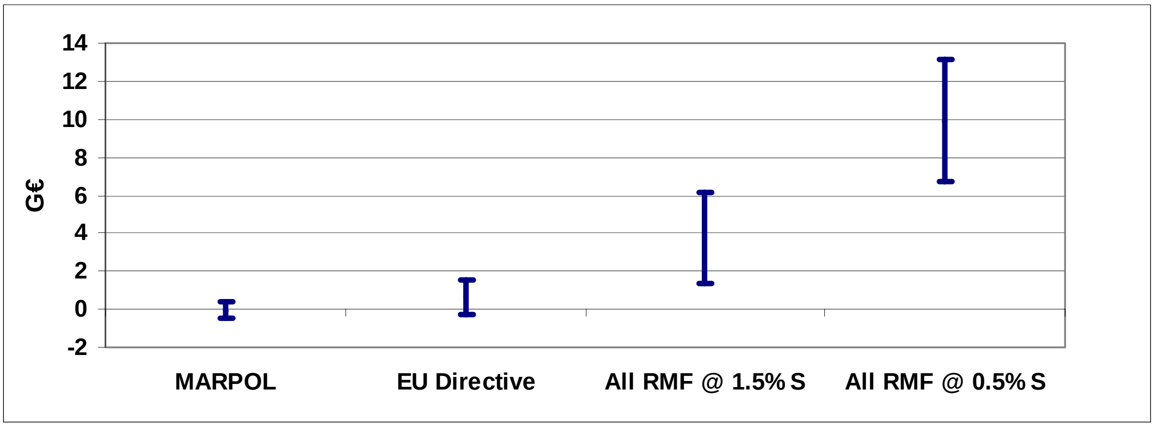


Figure 3 Annualised cost of LS RMF for implementation of sulphur limits (2015 demand basis)

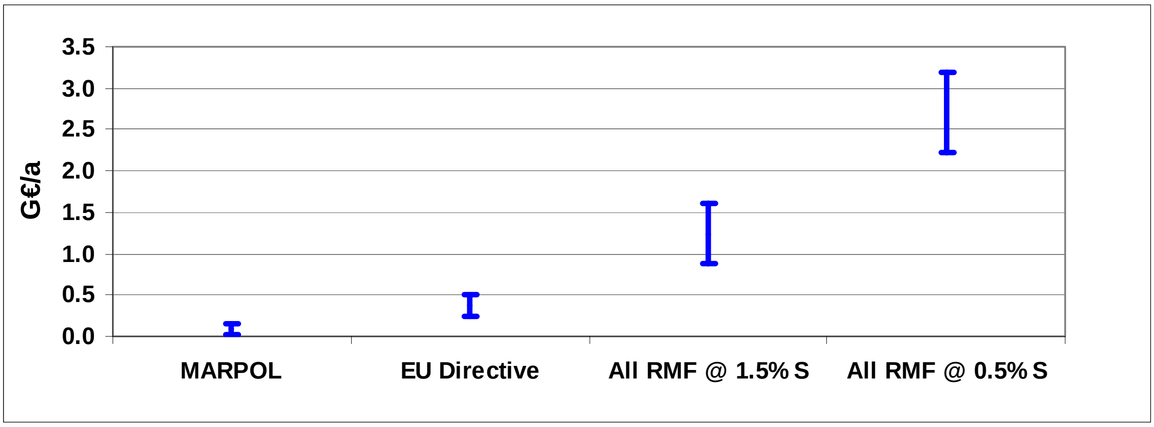
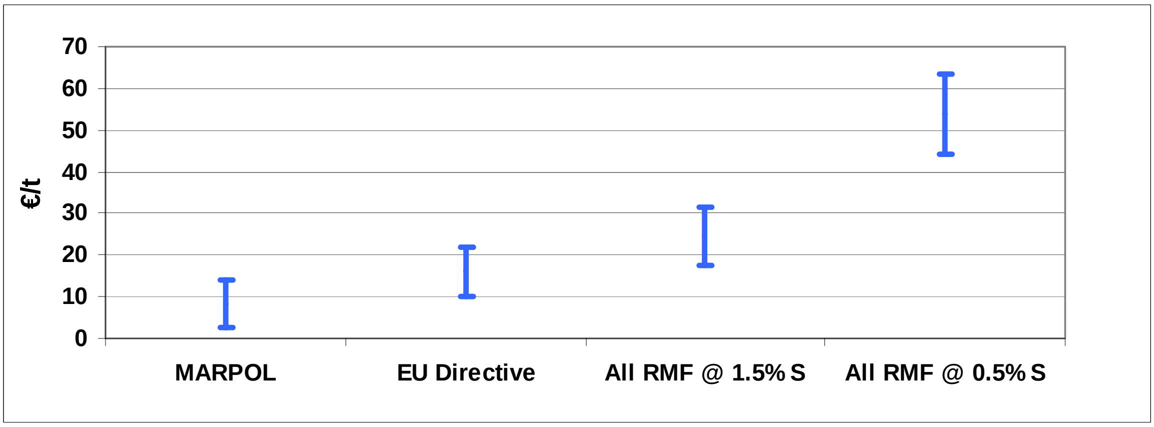


Figure 4 Cost per average tonne of LS RMF for implementation of sulphur limits (2015 demand basis)



Introduction of 1.5% sulphur RMF in the Baltic and North Sea SECAs creates a demand for LS RMF of 11 Mt/a. Including ferries results in a near doubling of that demand. The required investment increases notably between the two cases as the amount to be desulphurised and the difficulty of the task increase (most of the scope for segregation of low sulphur components and blending optimisation is taken up by the SECAs-only case). Operating costs increase more or less proportionally with LS RMF production. The total annualised cost increases sharply while the average cost of LS RMF roughly doubles.

The investment required for desulphurising the total RMF volume is much higher particularly so for the more stringent 0.5% S case. As illustrated in ***Table 6*** a lot more sulphur needs to be removed and it becomes increasingly difficult to do so. The cost reaches an average of 44-63 € per tonne of LS RMF.

Detailed plant utilisation data is shown in ***Appendix 3***. In order to meet the 2015 product demand and particularly to cater for a further shift towards middle distillates at the expense of gasoline, heavy investments in hydrocrackers is required. As sulphur restrictions become more stringent, the model gradually switches to investment in atmospheric residue desulphurisers. This maximises the flexibility of refineries by allowing the desulphurised residue to be used as feed to existing FCC capacity.

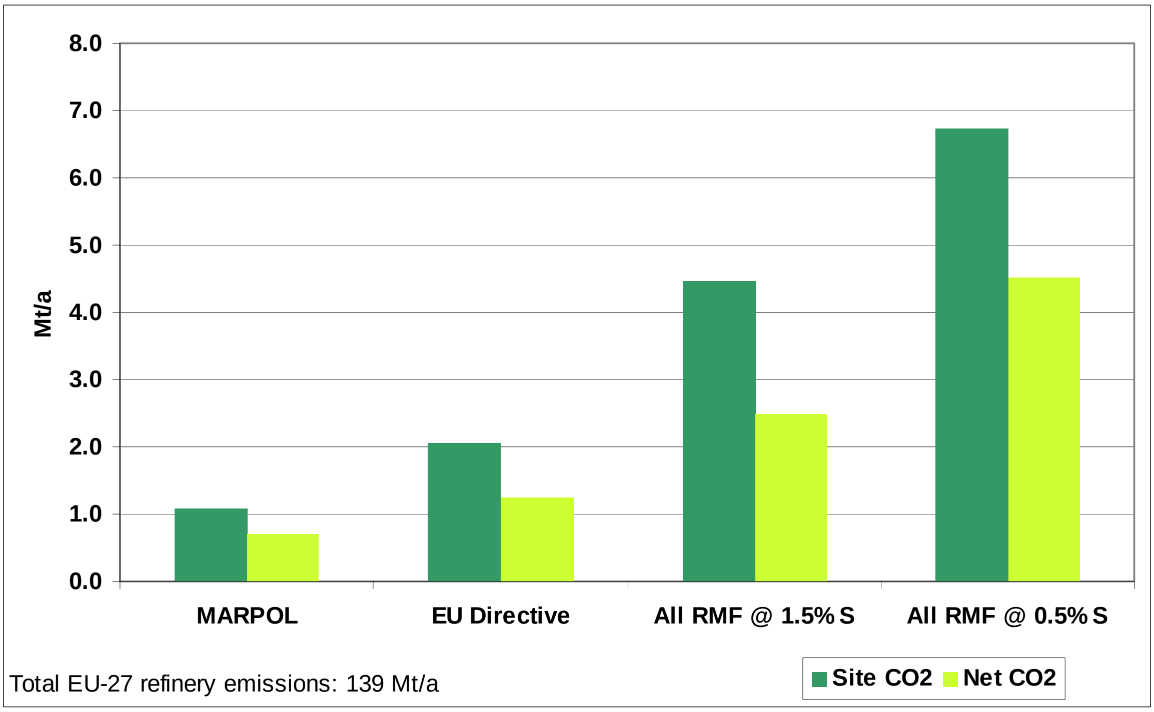
Table 6 Cost of sulphur removal

		MARPOL	EU Directive	All RMF @1.5% S	All RMF @0.5% S
Total sulphur removed (from reference)	*Mt/a*	*0.10*	*0.31*	*0.81*	*1.32*
Incremental sulphur removed			0.22	0.50	0.51
Average cost per tonne of sulphur removed		**1.6**	**1.6**	**2.0**	**2.4**
Incremental cost per tonne sulphur removed	**k€/t**		1.6	2.2	3.1

Not surprisingly the impact on CO_2 emissions is also very significant particularly for the most stringent scenario (***Figure 5***). The total increase of site emissions for all sulphur reduction measures is in the order of 6.5 Mt/a representing some 5% of the total EU refinery emissions.

On a global basis, part of that increase is, in principle, compensated by the slightly higher hydrogen content of the desulphurised products which therefore release less carbon when burnt. The net CO_2 effect remains significant at about 4.5 Mt/a in the most stringent case.

Figure 5 Increase of CO_2 emissions for implementation of sulphur limits (2015 demand basis)



5.2. EXERCISING REFINER'S OPTIONS: MAKE LS RMF, CONVERT RESIDUES, EXPORT HS HFO

The previous scenarios represent a situation where refineries are compelled to make the bunker demand. In reality each refiner is free to choose his preferred option and is likely to do so, as guided by economics. The costs estimated in the previous sections are therefore unlikely to be relevant in real life where the price of LS RMF will be determined by supply/demand influenced by the alternatives available to the refiners.

In this section we left the model free to either produce LS RMF at a given sulphur specification, or convert the surplus residual material, or again to produce surplus HS HFO for export (at a small discount of 5 $/t representing a notional cost of transport). We investigated three sulphur scenarios i.e.

- EU Directive (enacted legislation)
- All RMF at 1.5% sulphur
- All RMF at 0.5% sulphur

For each sulphur limit scenario we investigated the impact of the price differential between HS and LS RMF on the model response.

Reference price scenario

Referring back to ***Table 5*** we estimated the base price differential between LS and HS RMF to about 21 and 15 €/t in the reference and low price scenario respectively. The differentials between HS RMF and heating oil (the cheapest of the distillates) are 206 and 85 €/t respectively. ***Figures 6a/b*** show the response of the model in terms of RMF and export HFO production for each price scenario.

Figure 6a RMF and export HFO production
Reference price scenario

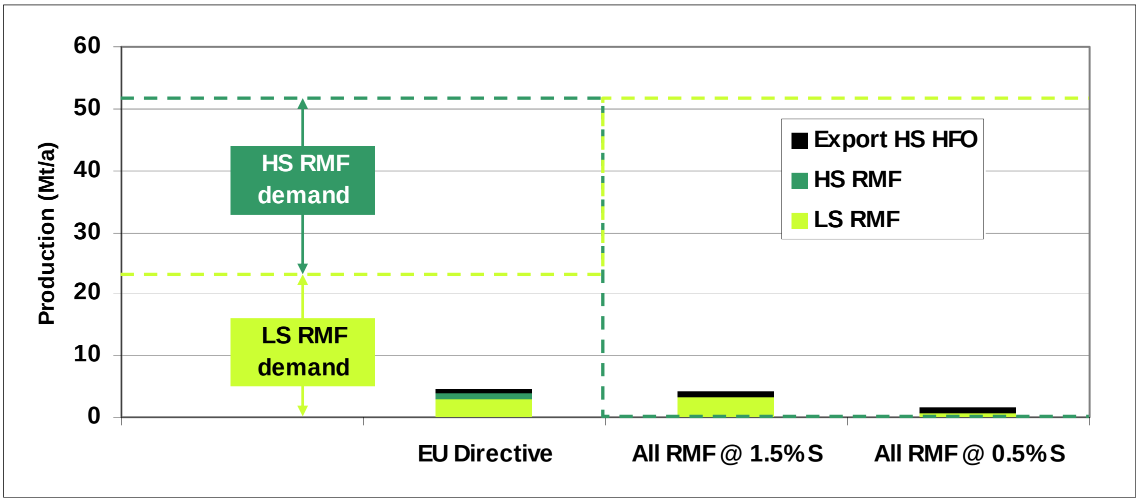
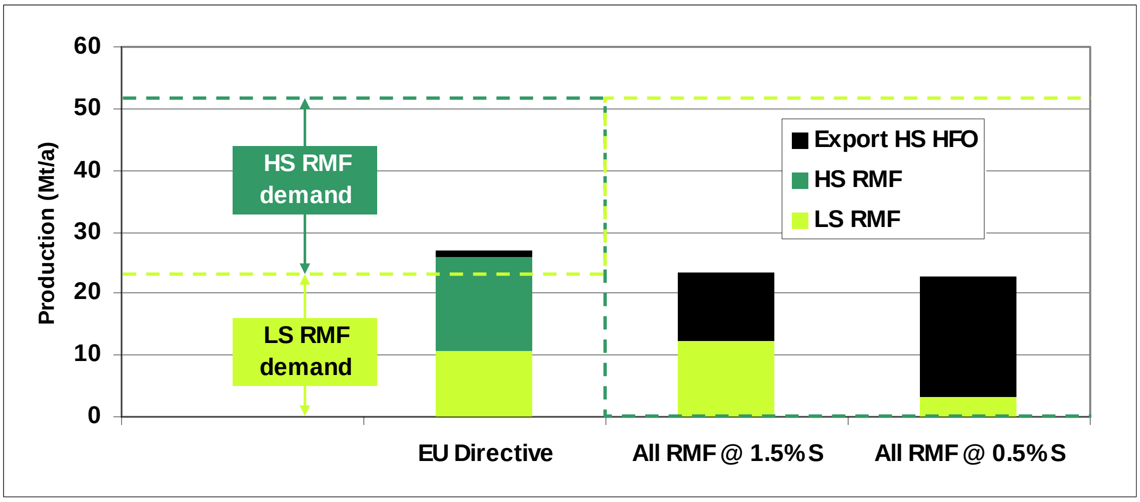


Figure 6b RMF and export HFO production
Low price scenario



In the reference price scenario (***Figure 6a***) there is virtually no production of either LS or HS RMF even in the EU Directive case and there is almost no export of HS HFO either (there is still some production of inland fuel oil not shown on the graph). The model provides significant new hydrocracking and atmospheric residue desulphurisation capacity to produce the required amount of distillates with less crude.

This means that, with these price differentials between residual fuels and distillates, investment in conversion units is attractive and more so than alternative investment in residue desulphurisation. This is of course not surprising when investment costs for desulphurisation facilities are only marginally lower than for conversion while the price differentials (LS-HFO v. distillate- HS HFO) differ by nearly an order of magnitude. In other words LS RMF is not valuable enough to be produced when compared to the alternative of conversion to distillates.

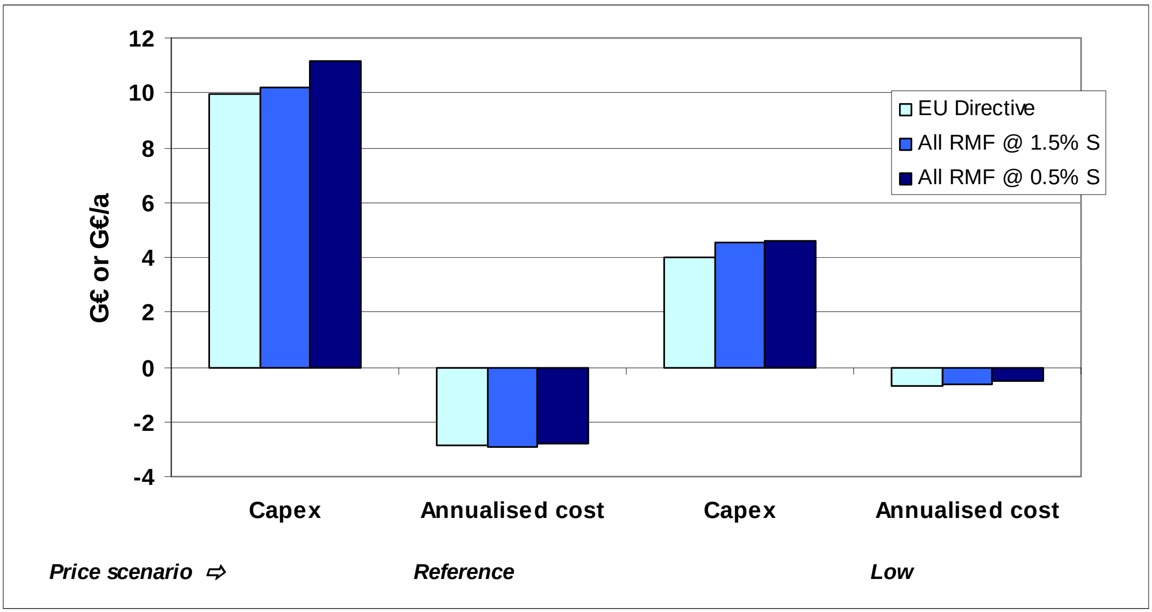
Even in the low price scenario (***Figure 6b***) and in EU Directive case, the production of both grades of RMF is far below the demand. When demand for HS RMF disappears in the last two cases, export takes over and the total RMF production remains well below the demand. At the 0.5% S limit, hardly any LS RMF is produced.

Refinery cost and CO_2 emissions

The "conversion solution" selected by the model optimiser maximizes margin. It does not, however, necessarily minimize investment. Indeed the higher margin is generated by using additional residue conversion facilities to produce the same distillate demand with less crude. This is illustrated in ***Figure 7*** which shows the extra capital investment and overall annualised cost relative to the reference case.

Inasmuch as this conversion option corresponds to optimisation of refinery economics we have used here the differential investment figures without regret investment. In terms of active plants, they should therefore be compared to the lower end of the ranges shown in ***Figure 2*** for the fixed demand cases.

Figure 7 Cost of conversion options above reference case

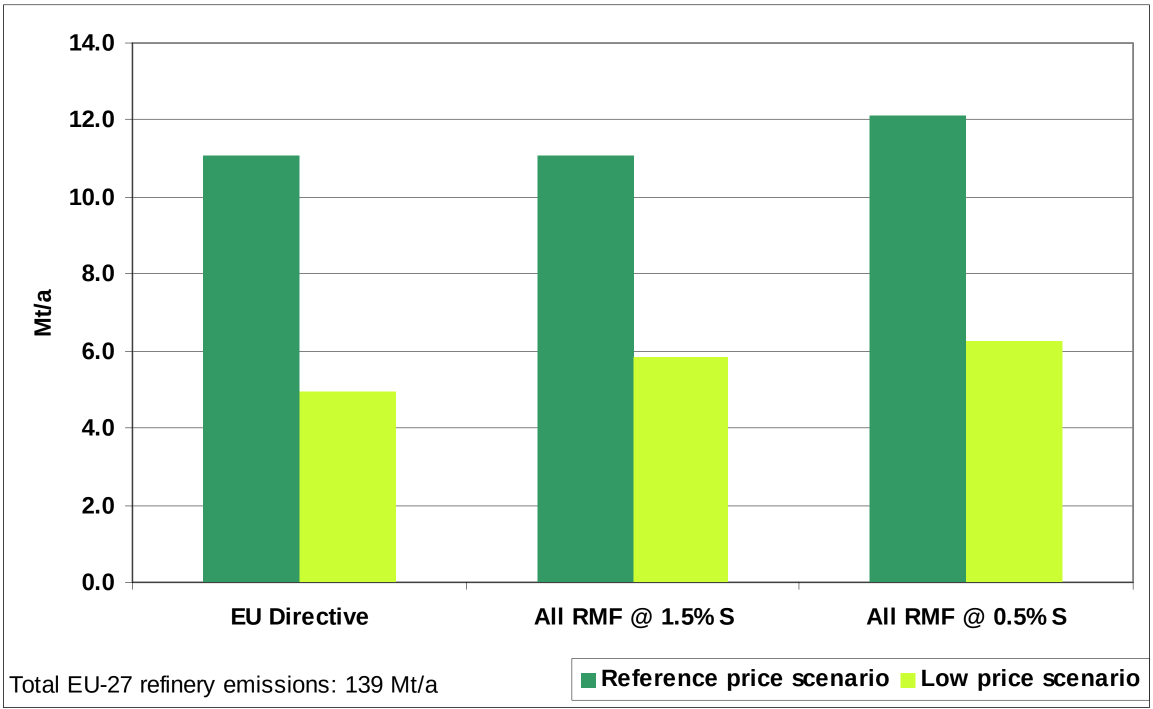


Compared to the reference case, the additional investment is in the order of 11 and 4 G€ in the reference and low price scenarios respectively, but this is more than compensated by a higher operating margin to yield a negative differential annual cost i.e. a more profitable operating case. In the low price scenario the lower driving force (price differentials) can only justify limited conversion. The investment is lower but so is the extra margin.

In the reference price scenario, the level of additional "active" investment is much higher than in the fixed demand cases (roughly 11 v. 7 G€) which can also be seen from the plant utilisation figures in ***Appendix 3 and 4***.

The additional processing also results in higher CO_2 emissions from the site, up to 12 Mt/a in the reference price scenario.

Figure 8 Refinery CO_2 emissions from conversion options above reference case



Note that the net CO_2 emissions are considerably lower than in the reference case (in the order of 140 and 80 Mt/a in the reference and low price scenarios respectively), simply because the refineries are only serving part of the market and delivering less products.

Varying the LS-HS differential

The previous scenarios are of course somewhat contrived as, with demand for LS RMF not satisfied, the market would obviously respond by a price increase relative to other products. The question is by how much should the LS RMF price increase to make LS RMF attractive over the conversion alternative. For each sulphur specification case and for each price scenario, we simulated an increasing LS-HS RMF differential, starting with the reference case. The response of the model is shown in ***Figure 9***. On the horizontal axis we have shown both the LS-HS RMF differential (the driving force for residue desulphurisation), and the heating oil - LS RMF differential (the driving force for conversion).

As the differential between LS and HS RMF increases so does LS RMF production. Desulphurisation of certain residues becomes more economic than conversion. The more stringent the sulphur limit, the higher the differential required to re-establish the full LS RMF demand.

Some HFO export occurs in the low price scenario but a higher price level justifies more conversion.

Figure 10 shows, in a summarised form the minimum LS-HS RMF differential required to justify making the full LS RMF demand in each of the sulphur limit and price scenarios. It also shows the corresponding heating oil - LS RM differential.

Figure 9 LS RMF production as a function of price (all options)

Reference price scenario ***Low price scenario***

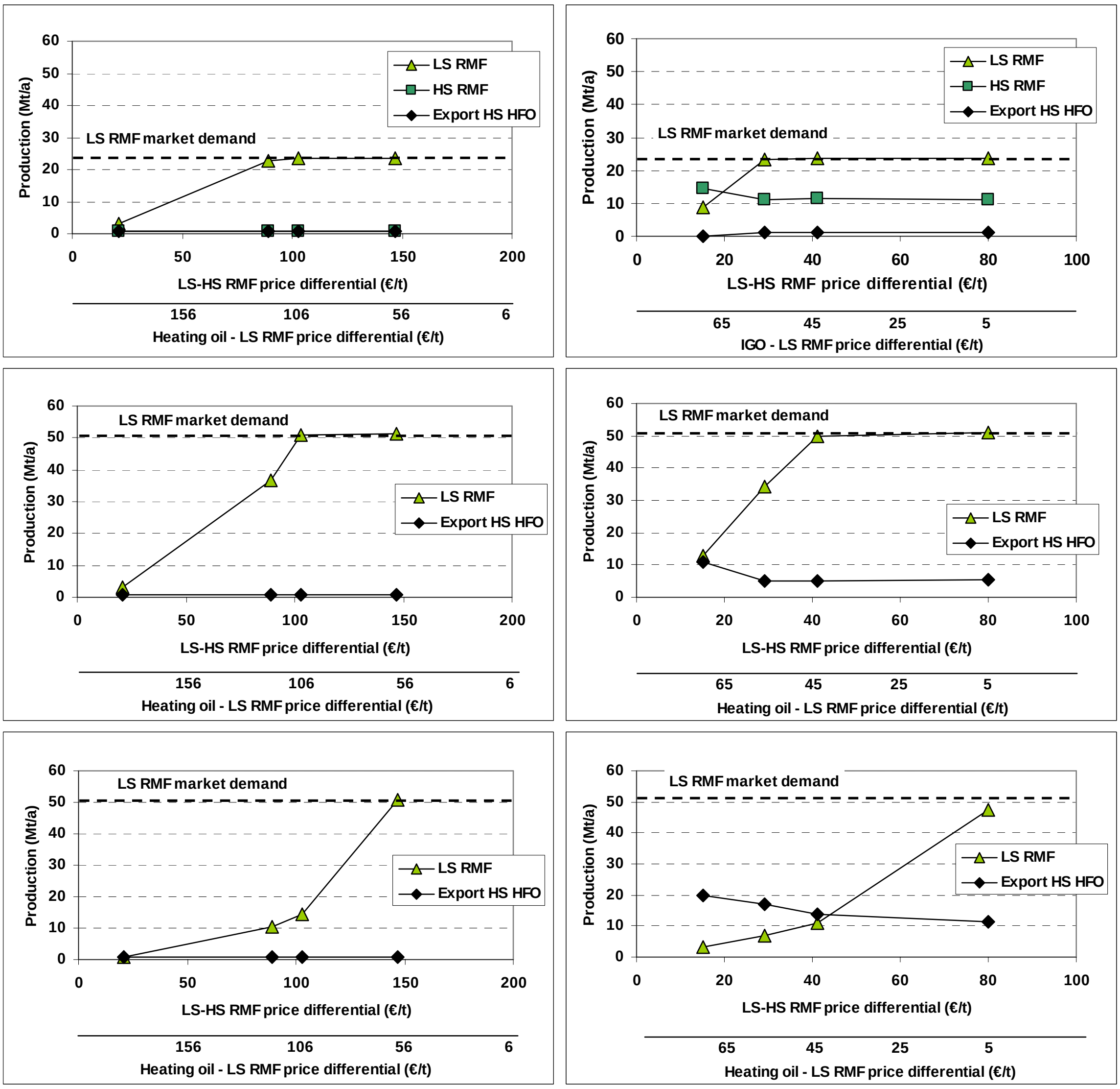
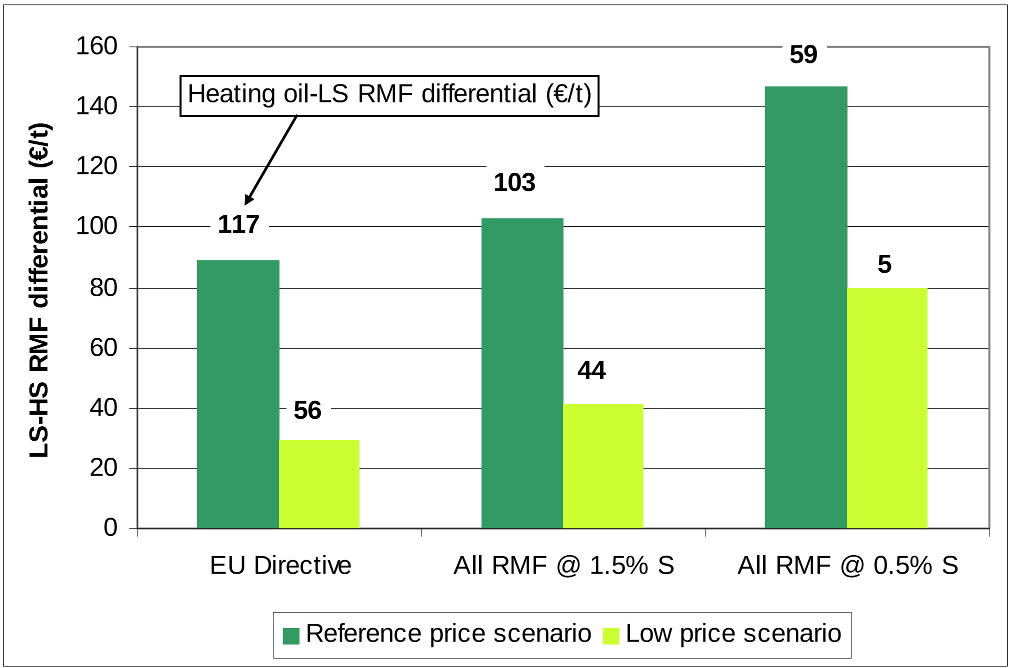


Figure 10 Minimum LS-HS RMF price differential for meeting full LS RMF demand (all options)



The LS-HS RMF differentials required to re-establish LS RMF production are extremely high. They are certainly much higher than the notional cost of desulphurisation estimated in section 5.1. In the most severe sulphur reduction scenario the required price of LS RMF comes close to that of heating oil. This is not a credible possibility as heating oil would of course remain a much more attractive fuel than RMF, even desulphurised.

These simulations illustrate the point made at the outset in section 3, namely that a severe sulphur specification changes the nature of RMF. It indeed becomes a product that needs to be "manufactured" and there are alternatives to this. The high prices indicated by our model suggest that there are more attractive economic alternatives.

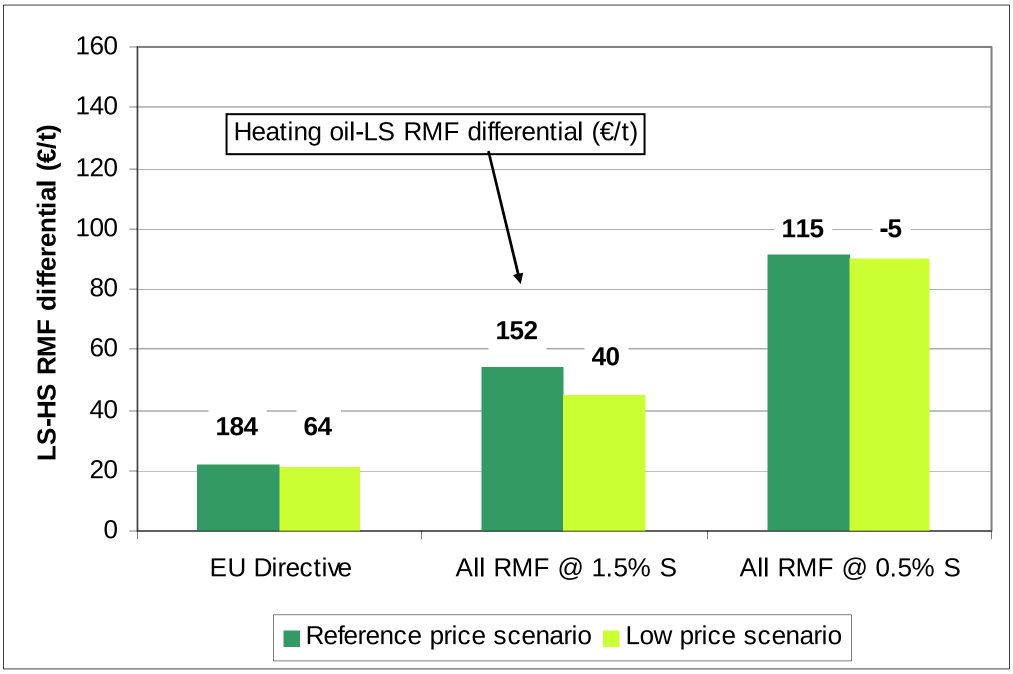
5.3. EXERCISING REFINER'S OPTIONS: MAKE LS RMF OR EXPORT HS HFO

In the above analysis the refiner's choice was essentially between two investment strategies i.e. desulphurise or convert. To complete the picture we analysed a "scarce resources" scenario where refiners would only invest to meet legislative demands. The model was required to produce the equivalent of the full RMF demand either as RMF at the required sulphur level or as export HFO.

As above we gradually increased the L-HS RMF differential until the full LS RMF demand was produced. ***Figure 11*** summarises the results in the same format as ***Figure 10***.

The first observation is that the required differential is hardly influenced by the price scenario. This was to be expected as the model is now purely driven by the cost of investment. Even in this case the required differential is higher than the notional cost estimated in section 5.1 although it must be noted that these figures are likely to be very sensitive to the net value of export HFO. This again illustrates the low economic attractiveness of the desulphurisation option.

Figure 11 Minimum LS-HS RMF price differential for meeting full LS RMF demand (no conversion option)



6. CONCLUSIONS

When faced with lower RMF sulphur specifications, EU refiners will have a number of options. Beyond the limited opportunities offered by stream segregation, blending optimisation and optimum crude selection, three main alternatives are available to deal with the refinery residual streams:

- Desulphurise residual streams to produce LS RMF,
- Convert residual streams to lighter products,
- Export HS HFO.

Desulphurisation is technically feasible but it has so far been used to produce feedstocks for conversion units and has not commonly been applied to produce commercial fuels including RMF. The processes involved are complex, the plants costly and delicate to operate and blended fuel stability and mutual compatibility can cause problems, especially with the heavier, higher sulphur residues. From an economic point of view it relies on the differential between low and high sulphur residual fuels which is only established on the basis of legislated sulphur limits.

Conversion also requires complex and costly plants but delivers distillate products that are inherently more valuable than residues. Its economic prospects are therefore much better than desulphurisation.

Residue desulphurisation has a high cost. Meeting already enacted legislation will require investments of up to 2 G€ in EU-27 whereas reducing the sulphur content of all RMF sold in Europe to 0.5% m/m would require an additional investment of between 7 and 13 G€. The average cost per tonne of LS RMF would be between 10 and 25 €/t to meet enacted legislation increasing to 45 to 65 €/t in the 0.5% sulphur case.

These costs, however, do no reflect the impact of the RMF sulphur limits on its likely market price. Indeed this study shows that, in all the cases studied and for LS RMF prices relative to other grades typical of today's markets, conversion or export would be more economically attractive for refiners than desulphurisation. The LS RMF price increase required to make desulphurisation attractive would be very high. In order to re-establish the full LS RMF production in our reference price scenario, differentials between HS and LS RMF in the order of 90 €/t would be required in the EU Directive case and up to 140 €/t in the 0.5% overall sulphur limit case. This would bring the price of LS RMF close to that of heating oil, which would then make LS RMF and unattractive customer choice.

APPENDIX 1 MATERIAL BALANCES

A.1.1 MATERIAL BALANCE 2005

	Total	EU-25	BAL	BNX	GER	CEU	UKI	FRA	IBE	MED
In	733.42	733.42	57.93	109.29	116.78	56.56	83.12	107.18	85.76	116.80
Crude	677.87	677.87	54.69	102.13	111.33	51.25	73.26	98.06	78.24	108.92
LS	313.50	313.50	30.04	50.76	61.62	8.11	52.12	34.51	20.98	55.37
HS	364.37	364.37	24.65	51.37	49.71	43.14	21.13	63.55	57.26	53.55
Other feeds and components										
Naphthas and mogas comp	8.80	8.80	0.00	3.30	1.90	0.10	0.40	1.00	1.80	0.30
Gasoils	27.90	27.90	2.80	3.80	2.10	1.20	5.00	9.80	3.20	0.00
Fuel Oils	9.50	9.50	0.00	5.70	0.00	0.00	0.00	0.00	0.00	3.80
Cracker feed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methanol	0.60	0.60	0.02	0.15	0.00	0.12	0.04	0.09	0.12	0.05
Ethanol	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	0.21	0.08	0.01	0.15	0.22	0.36	0.20	0.88
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	2.50	1.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00
Nat gas	3.00	3.00	0.46	0.00	0.00	0.00	0.00	0.52	0.71	1.32
Others	1.15	1.15	0.00	0.13	0.60	0.18	0.00	0.01	0.15	0.08
Transfers (Net In)										
Components	0.00	0.00	-1.24	-5.99	0.84	3.56	2.70	-2.67	1.34	1.45
Products	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Out	686.56	686.56	54.87	102.81	108.86	51.72	78.15	101.78	80.52	107.85
Main products										
LPG	20.94	20.94	1.89	3.06	2.78	1.34	3.03	3.63	1.70	3.50
Gasolines	138.58	138.58	13.18	16.37	21.64	12.81	17.99	18.20	12.98	25.42
Jet	54.94	54.94	6.42	5.80	6.44	0.23	15.56	8.74	5.46	6.29
AGO	183.35	183.35	11.39	28.10	30.64	15.87	11.62	26.67	25.03	34.03
IGO + gasoil comp.	110.44	110.44	8.62	18.77	18.97	11.71	8.50	18.84	11.85	13.18
LSFO	44.24	44.24	3.97	7.11	7.01	0.91	6.43	3.95	6.87	8.00
HSFO	45.68	45.68	3.62	9.83	2.60	1.51	4.28	10.20	7.30	6.34
Bitumen	20.00	20.00	1.70	0.70	3.10	2.70	2.30	3.50	2.60	3.40
Lubs and waxes	6.89	6.89	0.76	0.52	1.19	1.08	0.86	0.97	0.65	0.86
Coke	2.49	2.49	0.20	0.30	0.69	0.15	0.50	0.00	0.35	0.30
Electricity (TWh/a)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petrochemicals										
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	22.20	22.20	1.30	5.07	4.93	1.50	2.60	3.10	1.70	2.00
Propylene	15.60	15.60	0.82	3.10	3.54	0.96	2.03	1.85	1.39	1.91
C4 olefins	2.50	2.50	0.00	0.40	0.80	0.20	0.20	0.40	0.20	0.30
Benzene	8.61	8.61	0.48	2.05	1.84	0.20	1.06	1.01	1.15	0.82
Toluene	2.50	2.50	0.20	0.30	0.80	0.10	0.30	0.10	0.40	0.30
Xylenes	3.20	3.20	0.10	0.80	0.60	0.00	0.60	0.20	0.40	0.50
Methanol	0.70	0.70	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00
Miscellaneous										
Cracker feed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulphur	3.69	3.69	0.22	0.53	0.58	0.44	0.28	0.43	0.50	0.71
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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	46.86	46.86	3.05	6.48	7.92	4.85	4.97	5.39	5.24	8.95

A1.2 MATERIAL BALANCE 2015

	Total	EU-25	BAL	BNX	GER	CEU	UKI	FRA	IBE	MED
In	782.02	782.02	57.02	116.25	119.55	63.62	88.15	118.39	96.03	123.01
Crude	744.55	744.55	52.10	132.71	113.11	59.85	73.26	103.74	89.63	120.16
LS	332.30	332.30	33.89	55.77	64.70	9.01	54.69	40.88	21.45	51.92
HS	412.25	412.25	18.22	76.94	48.41	50.84	18.57	62.86	68.17	68.24
Other feeds and components										
Naphthas and mogas comp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gasoils	27.90	27.90	2.80	3.80	2.10	1.20	5.00	9.80	3.20	0.00
Fuel Oils	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cracker feed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methanol	0.62	0.62	0.04	0.13	0.00	0.10	0.04	0.08	0.12	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	2.10	0.46	0.00	0.00	0.00	0.17	0.28	0.42	0.77
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	2.50	1.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00
Nat gas	2.80	2.80	0.20	0.00	0.00	0.12	0.00	0.10	0.98	1.40
Others	1.55	1.55	0.00	0.21	0.66	0.23	0.02	0.09	0.22	0.12
Transfers (Net In)										
Components	0.00	0.00	0.41	-20.61	3.68	2.12	8.16	4.29	1.47	0.47
Products	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Out	729.91	729.91	53.93	108.46	111.07	58.13	83.01	111.83	89.93	113.55
Main products										
LPG	20.96	20.96	1.50	3.31	4.21	1.42	3.06	2.25	1.70	3.50
Gasolines	118.82	118.82	12.34	11.98	16.29	11.71	15.34	17.45	12.98	20.73
Jet	70.91	70.91	4.45	13.89	9.85	2.58	15.42	10.86	6.62	7.23
AGO	236.89	236.89	13.91	33.76	34.28	23.74	19.86	33.28	36.49	41.58
IGO + gasoil comp.	96.83	96.83	10.47	14.79	18.55	7.90	6.41	15.85	9.03	13.84
LSFO	44.03	44.03	5.10	8.22	6.39	0.00	7.72	5.98	3.57	7.06
HSFO	42.69	42.69	0.30	5.42	1.93	1.70	4.35	12.60	9.34	7.04
Bitumen	22.10	22.10	1.70	0.70	3.00	3.50	2.50	3.70	3.20	3.80
Lubs and waxes	6.80	6.80	0.76	0.43	1.19	1.08	0.86	0.97	0.65	0.86
Coke	2.48	2.48	0.20	0.30	0.70	0.15	0.50	0.00	0.35	0.30
Electricity (TWh/a)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petrochemicals										
Naphtha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethylene	24.50	24.50	1.40	6.38	4.92	1.70	2.60	3.50	1.80	2.20
Propylene	16.99	16.99	0.77	3.85	3.39	1.30	1.71	2.61	1.40	1.96
C4 olefins	3.20	3.20	0.00	0.50	1.00	0.20	0.20	0.60	0.30	0.40
Benzene	10.01	10.01	0.42	2.57	2.15	0.40	1.17	1.15	0.89	1.26
Toluene	2.50	2.50	0.20	0.30	0.80	0.10	0.30	0.10	0.40	0.30
Xylenes	5.20	5.20	0.20	1.40	1.10	0.10	0.70	0.40	0.60	0.70
Methanol	0.70	0.70	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00
Miscellaneous										
Cracker feed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulphur	4.29	4.29	0.22	0.67	0.63	0.56	0.31	0.52	0.61	0.78
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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	52.11	52.11	3.09	7.78	8.48	5.49	5.14	6.56	6.10	9.46

APPENDIX 2 COST OF IMPLEMENTATION OF SULPHUR LIMITS (2015 DEMAND BASIS)

		Reference	MARPOL	EU Directive	All RMF @1.5% S	All RMF @0.5% S
Nominal sulphur specification	*% m/m*					
LS RMF		*1.5*	*1.5*	*1.5*	*1.5*	*0.5*
HS RMF		*3.5*	*3.5*	*3.5*		
EU Refineries Production	*Mt/a*					
LS RMF		*0.0*	*11.6*	*23.4*	*50.8*	*50.2*
HS RMF		*51.8*	*40.1*	*28.0*	*0.0*	*0.0*
All figures are incremental from reference case						
With regret investment						
Capital Investment	M€		391	1563	6110	13121
Capital Charge @ 15%	M€/a		59	234	917	1968
Operating costs	M€/a		103	279	680	1214
Annualised costs	M€/a		**161**	**513**	**1596**	**3182**
Average cost per tonne of LS RMF	€/t		**14**	**22**	**31**	**63**
Total sulphur removed (from reference)	*Mt/a*		*0.10*	*0.31*	*0.81*	*1.32*
Incremental sulphur removed				0.22	0.50	0.51
Average cost per tonne of sulphur removed			1.6	1.6	2.0	2.4
Incremental cost per tonne sulphur removed	k€/t			1.6	2.2	3.1
No regret investment						
Capital Investment	M€		-464	-284	1353	6678
Capital Charge @ 15%			-70	-43	203	1002
Annualised costs	M€		**33**	**236**	**882**	**2215**
Average cost per tonne of LS RMF	€/t		**3**	**10**	**17**	**44**

APPENDIX 3 PLANT UTILISATION (FIXED DEMAND CASES)

	Total Plant Utilisation Mt/a					
	2005	2015				
	Base	Reference	MARPOL	EU Directive	All RMF @ 1.5%	All RMF @ 0.5%
CDU	677.9	744.3	744.6	744.7	745.2	745.9
HVU	260.5	286.0	287.5	280.7	255.6	235.4
Visbreaker	58.7	66.7	69.1	68.8	61.6	51.9
Del coker	12.7	12.8	12.8	12.7	12.5	12.8
C4 deasphalting	0.0	0.0				
FCC	123.5	116.1	118.0	119.4	123.5	121.9
Cracked gasoline splitter	32.3	25.7	27.6	28.7	29.6	29.6
HCU recycle	7.5	7.5	7.5	7.5	7.5	7.5
HCU once-through	48.9	94.9	89.6	83.7	66.6	56.0
Cat feed HT	23.0	12.2	17.6	20.9	23.0	23.0
LR HDS	4.6	4.6	4.8	9.4	29.1	62.3
VR HDS	1.3	1.3	1.3	1.3	1.3	1.3
Resid hydroconversion	5.1	5.1	5.1	5.1	5.1	5.1
Naph HT	82.1	79.2	78.2	78.0	76.7	78.9
Cracked gasoline HT	30.1	18.3	20.4	20.5	21.4	18.4
Cracked gasoline sweetening	0.8	0.8	0.8	0.8	0.8	0.8
Cat reforming (HP)	47.2	45.1	44.7	44.6	44.2	45.2
Cat reforming (LP)	37.2	37.3	37.2	37.2	37.2	37.1
Reformate splitter	26.9	42.1	41.7	41.2	35.5	29.9
Light reformate splitter	4.7	6.8	6.8	6.6	6.0	5.3
Aromatics Extraction	6.8	8.9	8.9	8.9	8.9	9.0
Alkylation	12.6	9.7	9.3	8.9	9.4	9.6
Isomerisation once-through	4.1	0.9	0.8	0.6	1.4	1.5
Isomerisation recycle	1.9	0.2	0.3	0.4		
MTBE	2.2	2.1	2.1	2.2	2.2	2.2
TAME	0.6	0.1			0.1	0.1
Butamer	0.1	0.0				
PP splitter	4.7	4.9	4.9	4.9	4.9	4.9
Kero HT	37.1	43.7	43.4	43.4	45.4	46.6
GO HT LP	18.8	19.1	19.1	19.1	19.1	19.1
GO HT MP revamp	140.2	172.7	173.9	174.7	177.6	178.1
GO HT HP	12.0	16.4	16.7	17.1	17.6	17.9
GO HDA	0.0	0.0				
SRU	4.0	4.6	4.7	4.9	5.6	6.2
FGDS	0.0	0.0	0.0	0.0	0.0	0.0
Bitumen	20.2	22.3	22.3	22.3	22.3	22.3
Lubs	3.2	3.2	3.2	3.2	2.8	2.8
Hydrogen manuf (as hydrogen)	0.5	*0.9*	*0.9*	*0.9*	*1.1*	*1.3*
Hydrogen scavenging	0.3	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*
POX + GT	0.9	0.9	0.9	0.9	0.9	0.9
IGCC	3.0	3.0	3.0	3.0	3.0	3.0
POX + hydrogen	0.0	0.0	0.0	0.0	0.0	0.0
POX + methanol	0.3	0.3	0.3	0.3	0.3	0.3
Steam cracker	66.8	74.1	74.2	74.1	74.2	74.1
Hydrodealkylation	0.0	0.0		0.0	0.0	0.1

APPENDIX 4 PLANT UTILISATION (CONVERSION CASES)

Reference price scenario

	Total Plant Utilisation Mt/a		
	EU Directive	All RMF @ 1.5%	All RMF @ 0.5%
CDU	700.3	699.9	697.7
HVU	262.0	260.9	262.0
Visbreaker	58.1	57.6	58.1
Del coker	12.8	12.8	12.8
C4 deasphalting			
FCC	109.8	110.0	108.9
Cracked gasoline splitter	21.6	21.6	20.6
HCU recycle	7.5	7.5	7.5
HCU once-through	124.0	124.0	126.7
Cat feed HT	6.8	5.8	3.3
LR HDS	29.1	30.0	27.7
VR HDS	1.3	1.3	1.3
Resid hydroconversion	8.1	8.1	10.5
Naph HT	70.8	70.9	70.7
Cracked gasoline HT	15.0	14.9	14.6
Cracked gasoline sweetening	0.8	0.8	0.8
Cat reforming (HP)	41.7	41.8	41.8
Cat reforming (LP)	37.0	37.0	36.8
Reformate splitter	39.0	39.2	39.0
Light reformate splitter	6.4	6.4	6.4
Aromatics Extraction	8.8	8.8	8.8
Alkylation	10.3	10.3	10.5
Isomerisation once-through	0.6	0.6	0.6
Isomerisation recycle			
MTBE	2.2	2.2	2.2
TAME	0.2	0.2	0.2
Butamer	0.0	0.0	0.1
PP splitter	4.9	4.9	4.9
Kero HT	40.2	40.3	40.8
GO HT LP	19.1	19.1	19.1
GO HT MP revamp	164.4	164.3	163.4
GO HT HP	13.8	13.7	13.6
GO HDA			
SRU	5.2	5.2	5.2
FGDS	0.0	0.0	0.0
Bitumen	22.3	22.3	22.3
Lubs	2.8	2.8	2.8
Hydrogen manuf (as hydrogen)	*1.4*	*1.4*	*1.4*
Hydrogen scavenging	*0.3*	*0.3*	*0.3*
POX + GT	0.9	0.9	0.9
IGCC	3.0	3.0	3.0
POX + hydrogen	0.0	0.0	0.0
POX + methanol	0.3	0.3	0.3
Steam cracker	74.6	74.6	74.6
Hydrodealkylation			

Low price scenario

	Total Plant Utilisation Mt/a		
	EU Directive	All RMF @ 1.5%	All RMF @ 0.5%
CDU	721.6	718.3	717.6
HVU	280.5	276.2	278.5
Visbreaker	67.6	65.6	66.5
Del coker	12.7	12.7	12.7
C4 deasphalting			
FCC	115.7	116.0	114.7
Cracked gasoline splitter	27.6	27.7	26.5
HCU recycle	7.5	7.5	7.5
HCU once-through	100.9	101.2	105.2
Cat feed HT	22.3	22.3	23.0
LR HDS	15.7	19.5	17.2
VR HDS	1.3	1.3	1.3
Resid hydroconversion	5.1	5.1	5.1
Naph HT	76.0	75.5	74.9
Cracked gasoline HT	20.0	19.2	19.1
Cracked gasoline sweetening	0.8	0.8	0.8
Cat reforming (HP)	42.9	42.7	41.9
Cat reforming (LP)	37.2	37.2	37.2
Reformate splitter	41.7	41.3	41.2
Light reformate splitter	6.8	6.8	6.8
Aromatics Extraction	8.9	8.9	8.9
Alkylation	9.9	10.1	10.1
Isomerisation once-through	0.6	0.5	0.7
Isomerisation recycle			
MTBE	2.1	2.2	2.2
TAME			
Butamer	0.0	0.0	0.0
PP splitter	4.9	4.9	4.9
Kero HT	40.1	39.7	40.0
GO HT LP	19.1	19.1	19.1
GO HT MP revamp	172.3	171.9	170.6
GO HT HP	14.1	13.8	13.9
GO HDA			
SRU	5.0	5.1	5.0
FGDS	0.0	0.0	0.0
Bitumen	22.3	22.3	22.3
Lubs	3.0	2.9	3.0
Hydrogen manuf (as hydrogen)	*1.2*	*1.2*	*1.2*
Hydrogen scavenging	*0.3*	*0.3*	*0.3*
POX + GT	0.9	0.9	0.9
IGCC	3.0	3.0	3.0
POX + hydrogen	0.0	0.0	0.0
POX + methanol	0.3	0.3	0.3
Steam cracker	74.3	74.3	74.3
Hydrodealkylation			