ULS GASOLINE AND DIESEL REFINING STUDY

Prepared For

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I. INTRODUCTION

Purvin & Gertz was requested by the European Commission to study the cost implications of producing Ultra Low Sulfur (ULS) gasoline and diesel. For the purposes of this study ULS gasoline and diesel is defined as gasoline and diesel with 30 ppm sulfur content or lower. The main focus is on fuels of below 10 ppm sulfur content. Purvin & Gertz' approach to this study and the scope of work was shown in its proposal of the 3rd August 2000 to Directorate General ENV3. The approach is based on assessment of the cost of production of 10 ppm sulfur gasoline and diesel in comparison to a Base Case of 50 ppm gasoline and diesel using Purvin & Gertz' yardstick Northwest Europe and Mediterranean catalytic cracking refineries. Around 75% of EU15 refining capacity is of a catalytic cracking configuration.

The underlying assumptions for demand, quality and supply of refined products in the European Union are based on information extracted from Purvin & Gertz' multiclient study "European Refining to 2015: The Quality Challenge" completed last year. A discussion of the Base Case assumptions is provided in the Appendix of this report.

The report provides a summary of results in Section II. The methodology used in the study is described in Section III. A review of the technologies likely to be considered by refiners to produce ULS fuels is provided in Section IV. A description of the cases considered is provided in Section V. Finally, the economic results of the study are provided in Section VI.

The study was based on the assessment of costs of production of ULS fuels in catalytic cracking refineries. The costs shown are applicable to the costs incurred by refineries and do not take account of any cost implications in the downstream distribution and marketing network.

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II. SUMMARY

Purvin & Gertz' approach to this study relies heavily on earlier analysis carried out in its multiclient study "European Refining to 2015: The Quality Challenge". The underlying assumptions for this study were based on the multiclient study. The study is based on analysis of investment requirements and operational changes required to move from 50 ppm gasoline and diesel to 10 ppm gasoline and diesel. The evaluation has been made using Purvin & Gertz' yardstick catalytic cracking refineries. It was assumed that to produce a saleable 10 ppm product, the ULS gasoline and diesel produced in the refinery would need to be around 6 to 7 ppm. The yardstick refineries were developed by Purvin & Gertz based on production of 50 ppm gasoline and diesel to assist its analysis of refined product prices and refining margins in the main two pricing regions in Europe namely Northwest Europe and the Mediterranean. The yardstick refineries aim to represent competitive refining capacity in the region in terms of yields and operating costs.

Purvin & Gertz has concentrated on the catalytic cracking refinery configuration. It is expected that catalytic cracking refineries will incur the highest incremental costs in moving from 50 ppm fuels to 10 ppm fuels. As a result we expect the catalytic cracking refinery configuration to set prices of ULS gasoline and diesel relative to 50 ppm gasoline and diesel.

It is well recognized that each individual refinery in the European refining system will incur significantly different costs on an individual basis for production of ULS fuels. To reflect this variation in investments, Purvin & Gertz has considered a range of investments which might be expected for catalytic cracking refineries. There are a large number of factors which will affect an individual refineries' investment including the factors identified below.

MAIN FACTORS INFLUENCING ULS FUEL INVESTMENT COSTS

Factor	Lower Costs →	Higher Costs	Product Cost Affected
Crude Slate	Lower Sulfur	Higher Sulfur	Gasoline/Diesel
Diesel/Gasoil split	More gasoil	More diesel	Diesel
Refinery Configuration	Hydroskimming/hydrocracking	Cat. Cracking	Gasoline/Diesel
Existing Hydrotreater Pressure	Higher Pressure	Lower Pressure	Diesel
Reformer type	CCR	Semi-Regen	Gasoline/Diesel

The approach of the study was to identify discreet investments and operating costs associated with the reduction in sulfur content of gasoline and diesel from 50 ppm to 10 ppm whilst maintaining the yields of the major products. In fact many refiners may accept some yield degradation to minimize capital investment. Some refiners may make larger investments than that needed merely to reduce sulfur content to improve yields. These types of investments will have an impact on the overall supply/demand balance of products in Europe. If these investments result in a supply/demand balance change in Europe the relative product prices will change accordingly and refinery profitability will be affected through the change in the value of the product rather than investment and operating costs. Ultimately the overall costs to the industry taking into account yield deterioration, investment and operating cost are expected to be similar to the approach used in this study which is to make investments to maintain the yield profile.

REVIEW OF CASES

The cases considered by Purvin & Gertz in the study are briefly described below.

GASOLINE

A combination of investments to produce ULS gasoline were identified. Firstly modifications to the light Fluid Catalytic Cracker (FCC) gasoline sweetening unit would be expected to be made to remove more sulfur. Similarly, the sweetening processes used for LPG streams would be modified to increase the removal of sulfur since butane and LPG derived gasoline components such as alkylate and MTBE can contain sulfur in the 20 to 30 ppm range. Once these relatively low cost changes are made, hydrotreating of the remaining FCC gasoline would be undertaken. It is expected that an FCC gasoline treating process which limits octane loss would be used. This technology is still under development but the Base Case assumes such a process is used for production of 50 ppm gasoline. Moving to 10 ppm will require an increase in severity of the hydrotreater operation with some associated further octane loss.

Some refineries may not have invested in a dedicated FCC gasoline hydrotreater to meet the 50 ppm specification. As a result, they would be faced with somewhat higher costs when moving to 10 ppm sulfur content as this would entail installation of a grassroots FCC gasoline hydrotreater. For some refineries processing high sulfur content crude slates, the modification described above may not be sufficient to enable production of 10 ppm gasoline. These refineries may need to consider investment in sulfur removal upstream of the FCC unit as well as the downstream treatment described above. The capital cost for FCC feed pretreatment is significantly higher but in most cases results in an overall yield benefit to the refinery which may make the investment economically attractive.

DIESEL

Purvin & Gertz' yardstick refineries for production of 50 ppm diesel assume that a medium pressure diesel hydrotreater operating in the 50 to 60 bar range is already installed. For the yardstick refineries, it is expected that a revamp of this type of unit would be sufficient to enable production of 10 ppm diesel. The revamp would involve installation of additional catalyst volume, more active catalyst, and some improvement to hydrogen purification and production facilities.

Most refineries produce both diesel and heating gasoil. Refineries which produce a higher proportion of diesel than that assumed in the yardstick refineries will need to use some light cycle oil (LCO) in the production of diesel. LCO is produced from the FCC unit and is considerably more difficult to desulfurize than most other diesel blending components. In addition, refiners processing higher sulfur content crudes than in the yardstick assumption will not be able to produce ULS diesel using the investments discussed above. Refineries facing these constraints will likely have to invest in higher pressure hydrotreating, in the range 90 to 100 bar, to achieve the less than 10 ppm diesel sulfur content.

In all cases, we have assumed some increase in capacity of the diesel hydrotreater will be required due to the difficulties in making and segregating ULS diesel production. The potential for contamination of less than 10 ppm product is extremely high and it is likely that some products will be contaminated from time to time and this will have to be downgraded to heating gasoil. The ability to correct an off specification product tank is much reduced when the sulfur content is reduced to levels as low as 10 ppm. Consequently, we have allowed for some extra capacity in the diesel hydrotreater to allow for these operational upsets.

ECONOMIC RESULTS

Purvin & Gertz has used two approaches to expressing the economic results of the study. Firstly, the operating and capital costs have been combined as a Net Present Value (NPV) in line with the European Commission's request. The NPV was then converted to a cost in € per tonne of product. Secondly, Purvin & Gertz has used its own approach to estimating the price premium for higher specification fuel compared to current quality. Purvin & Gertz has successfully used this approach in the past when new product specifications have been introduced. Our opinion is that the price premium approach provides a more reliable indicator of the implications of production of ULS fuels as it avoids the anomaly of applying a discount rate to a stream of future costs with no offsetting revenue. The results are summarized in the table below.

ECONOMIC RESULTS

	Northern Europe		Southern Europe	
	Gasoline	Diesel	Gasoline	Diesel
Cost, €/tonne				
@ 4% Discount Rate	1-2	3-5	2-4	5-7
@ 7% Discount Rate	1-2	3-5	2-4	5-7
Auto Oil 1 Approach (1)	1	3-5	2-4	5-7
Price Premium €/tonne	1-3	4-7	2-4	7-10
Cost Cents per litre				
@ 4% Discount Rate	0.1-0.2	0.3-0.4	0.2-0.3	0.4-0.6
@ 7% Discount Rate	0.1-0.2	0.3-0.4	0.2-0.3	0.4-0.6
Auto Oil 1 Approach (1)	0.1	0.3-0.4	0.2-0.3	0.4-0.6
Price Premium c/litre	0.1-0.3	0.3-0.6	0.2-0.3	0.6-0.9

Note : (1) (Capex + 9.75*Annual Opex)/(15 years production)

Purvin & Gertz has observed previously that when new product specifications are introduced refineries which are able to produce the new grade using relatively low cost solutions can achieve a reasonable return on capital. Refineries requiring extensive modifications, such as grassroots process unit investments, are only able to achieve a low rate of return. Using this approach we have estimated a range of price premia in the two regions.

For gasoline, the price premium in Northern Europe is expected to be relatively low in the €1 to €3 per tonne of product as the investments required are relatively minor. A slightly higher level in the €2 to €4 per tonne range is expected in the South due to the higher sulfur content feedstocks processed.

The price premium for ULS diesel versus 50 ppm diesel is expected to be somewhat higher. In Northern Europe, the premium is expected to be in the €4 to €7 per tonne range. In the South, the higher sulfur content crude slate and higher proportion of diesel in the diesel/gasoil mix results in a somewhat higher premium of €7 to €10 per tonne.

III. METHODOLOGY

Purvin & Gertz' approach to this study relies heavily on earlier analysis carried out in its multiclient study "European Refining to 2015: The Quality Challenge". The underlying assumptions for this study were based on the multiclient study. Assumptions underlying the Base Case are provided in the Appendix and are mainly extracted from the multiclient study with an updated price forecast.

The ULS gasoline and diesel study is based on analysis of the investment requirements and operational changes required to move from 50 ppm sulfur gasoline and diesel to 10 ppm sulfur gasoline and diesel using Purvin & Gertz' "yardstick" refineries described below. It is assumed that to produce a saleable 10 ppm product, the ULS gasoline and diesel produced in the refinery would need to be around 6 – 7 ppm.

PURVIN & GERTZ YARDSTICK REFINERIES

As part of its analysis in the "European Refining to 2015" study, Purvin & Gertz developed yardstick refineries for the Northwest Europe and Mediterranean regions. These yardstick refineries were developed to be used in Purvin & Gertz' analysis of refined product prices and refining margins in the two main pricing regions in Europe namely Northwest Europe and the Mediterranean. The yardstick refineries aim to represent competitive refining capacity in the region in terms of yields and operating costs. Three types of yardstick refinery were developed for each region, hydroskimming, catalytic cracking and hydrocracking.

The production of ULS gasoline is much more difficult for catalytic cracking refinery configurations than for hydroskimming or hydrocracking. The main source of sulfur in European gasoline is from the gasoline produced from the catalytic cracker itself. Hydroskimming and hydrocracking refineries produce gasoline which is more or less sulfur free. As a result, the price of ULS gasoline is likely to be set by consideration of the production costs from catalytic cracking refineries in Europe. In addition, the bulk of refining capacity in Europe is catalytic cracking based representing around 75% of capacity. Purvin & Gertz has concentrated on the catalytic cracking configuration and has used its yardstick catalytic cracking refineries for the assessment of incremental production costs of ULS gasoline.

The main components for diesel production in Europe are straight run material produced from crude distillation, diesel produced from hydrocrackers, and cracked gasoil materials produced from catalytic cracking and thermal cracking processes. Since crude distillation is utilized in all refineries, the straight run diesel treatment for ULS diesel production is common to all configurations. Diesel produced from a hydrocracker is generally very low in sulfur content and in many cases would meet the 10 ppm sulfur content specification without any additional treatment. The cracked gasoil streams produced from catalytic cracking and thermal cracking processes are generally much higher in sulfur content than straight run material and are also relatively difficult to hydrotreat for removal of sulfur. As a result, it is expected that catalytic cracking refineries will also face the most significant investment for production of ULS diesel and we have also considered the yardstick catalytic cracking refineries for analysis of production costs of ULS diesel.

The base case yardstick refinery configurations, feedstock bases and yields developed by Purvin & Gertz are shown in Table III-1. The configurations shown are based on production of gasoline with 50 ppm sulfur content and 35% maximum aromatic content and diesel with 50 ppm sulfur content and all other specifications at the current levels.

The Northwest Europe yardstick is based on a capacity of 180,000 B/D and is considered to be a competitive size in the region. The capacity of the downstream facilities are sized based on the LP optimization. The gasoil hydrotreater is assumed to remove 99.0% of the sulfur in straight run gasoil and 95% of the sulfur in cracked gasoil. We envisage that such a hydrotreater would be designed for operation at a pressure of around 55 bar. Production of 50 ppm gasoline is achieved by reducing the back end cut point of the catalytic cracker gasoline, installation of a FCC gasoline splitter and hydrotreating of a portion of the FCC gasoline.

The crude slate assumed for the Northwest Europe yardstick is 70% Brent/30% Arabian Light crude. Brent is used as representative of a light sweet crude and Arabian Light as representative of a light sour crude. The crude slate is based on the typical crude slate in the Northern Europe refining region. However, the proportion of sweet crude is somewhat higher than the Northern Europe average as we have assumed that the hydrocracking refineries in the region would generally process a higher proportion of light sour crude than the regional average and the catalytic cracking refineries would process a higher proportion of sweet crude than the average.

The yield split for the gasoline grades has been set to match approximately with the split in gasoline demand requirements by grade based on Purvin & Gertz’ demand projections. Similarly the split between diesel and heating gasoil has also been set to be in line with market requirements.

The Mediterranean yardstick refineries are based on a capacity of 150,000 B/D and are considered to be of competitive size in the region. As in Northwest Europe, the capacity of the downstream facilities are based on the LP optimization. An important difference between the Mediterranean yardstick and the Northwest European yardstick is the higher sulfur content crude slate assumed. In the Mediterranean the yardstick is based on a mix of 40% Brent quality and 60% Arabian Light quality. In addition, the higher percentage of diesel in the diesel/gasoil production results in a requirement to remove more sulfur to meet the sulfur content specifications. This is indicated by the ratio of the gasoil hydrotreater capacity to the crude distillation capacity in the Mediterranean yardstick compared to the Northwest Europe yardstick. The capacity of the gasoil hydrotreater in the Mediterranean yardstick is almost as great as that for Northwest Europe but for a crude capacity of nearly 17% lower.

The investments required to meet 50 ppm sulfur content gasoline and diesel are broadly similar to those in the Northwest European yardstick. However, due to the higher sulfur content of the feedstock the capacities are generally somewhat higher relative to crude capacity in the Mediterranean than in Northwest Europe. In addition, our Mediterranean yardstick assumes use of a semi-regenerative catalytic reformer, and this combined with the higher sulfur content feedstock, results in a greater requirement for additional hydrogen production. As a result, we show a larger hydrogen plant required in the Mediterranean yardstick refinery to enable production of 50 ppm sulfur content gasoline and diesel.

The approach used to estimate the incremental costs of production of gasoline and diesel in comparison to production of 50 ppm quality is based on the investment requirements and associated operating cost changes needed to produce the ULS product while maintaining the major product yields produced from the refineries.

INDUSTRY CONTACTING

Purvin & Gertz contacted a number of key organizations in the industry to further improve its knowledge and understanding and to discuss the latest technology developments and important issues with respect to reduction of gasoline and diesel sulfur content below 50 ppm. Purvin & Gertz was not able to contact all major organizations in the time available for the study but undertook detailed discussions with the following companies and organizations.

ORGANIZATIONS CONTACTED
Akzo Chemie
Concawe
Repsol
Saras
Shell
TotalFinaElf
UOP

Purvin & Gertz also attempted to contact Agip Petroli, BP and ExxonMobil but was not able to set up meetings in the time available. We would like to thank the above organizations for their time and assistance with this study.

RANGE OF INVESTMENT REQUIREMENTS

Purvin & Gertz' approach to this study is focused on its Northwest Europe and Mediterranean yardstick catalytic cracking refineries. It is well recognized that every individual refinery will see different costs to meet 10 ppm gasoline and diesel. As a result, we have developed a range of investment requirements which would cover most of the refineries in the EU15.

The main factors affecting the cost of production of ULS gasoline and diesel and their directional effect on the costs are summarized below:

MAIN FACTORS INFLUENCING ULS FUEL INVESTMENT COSTS

Factor	Lower Costs →	Higher Costs	Product Cost Affected
Crude Slate	Lower Sulfur	Higher Sulfur	Gasoline/Diesel
Diesel/Gasoil split	More gasoil	More diesel	Diesel
Refinery Configuration	Hydroskimming/hydrocracking	Cat. Cracking	Gasoline/Diesel
Existing Hydrotreater Pressure	Higher Pressure	Lower Pressure	Diesel
Reformer type	CCR	Semi-Regen	Gasoline/Diesel

As a result, the investment requirements for our Northwest Europe catalytic cracking refinery yardstick are likely to be toward the lower end of the range but not as low as for most hydroskimming or hydrocracking refineries. The investment requirements for our Mediterranean catalytic cracking refinery yardstick are likely to be toward the higher end of the range.

OTHER FACTORS AFFECTING INVESTMENTS

The approach to the study was to identify discreet investments and operating costs associated with the reduction in sulfur content of gasoline and diesel from 50 ppm to 10 ppm. In practice, many refiners will achieve these reductions in conjunction with some other investments needed for other purposes. For example, a catalytic cracking refinery may consider adding some hydrocracking based process to address the shift in demand from gasoline to diesel. The addition of such a process will also assist the refiner in producing ULS gasoline and diesel. However, there will still be some incremental cost of production of ULS gasoline and diesel versus the 50 ppm product. Since the addition of hydrocracking facilities would shift the yield slate of the refinery significantly, the price assumptions regarding the relative prices of products becomes overwhelming in the economics. Also the yield shift has supply/demand balance implications. Overall the analysis becomes significantly more complex and is not helpful in understanding the incremental costs of producing ULS gasoline and diesel.

A refinery investment such as that described above would result in an improvement in the refinery yield slate. An alternative approach taken by many refiners when meeting new specifications is to accept a deterioration in yields if it avoids capital investment. For example, a refiner many accept a reduction in diesel yield and increase in lower quality heating gasoil yield to avoid capital expenditure to meet a change in diesel specifications. Many refiners have adopted this approach in meeting the year 2000 gasoline and diesel specifications. In overall industry terms, adopting such an approach would reduce the supply of diesel and increase the supply of heating gasoil. The supply/demand balance for diesel in Europe would tighten and diesel prices would increase until alternative supplies could be imported or the price spread between diesel and gasoil increased to a high enough level for more refineries to invest to produce additional diesel. Ultimately the overall cost to the industry taking into account yield deterioration, investment and operating costs is expected to be similar to the approach used in this study which is to make investments to maintain the yield profile.

We have considered the catalytic cracking refineries in isolation in this study. Many companies own multiple refinery systems some of which are close enough to consider the exchange of unfinished products. For example, a hydroskimming refinery which may have difficulty meeting the year 2005 35% aromatics gasoline specification may exchange reformate for FCC gasoline to dilute the aromatics. At the same time, the exchange helps the catalytic cracking refinery by exchanging high sulfur content FCC gasoline for low sulfur content reformate. Refiners will take advantage of such exchanges where economic within their own refining systems or with other companies.

TABLE III - 1
PURVIN & GERTZ' 2005 YARDSTICK
CATALYTIC CRACKING REFINERIES

	NW Europe		Mediterranean	
Unit Capacities	kt/year	kb/sd	kit/year	kb/sd
Crude Distillation	8160	180	6670	150
Vacuum Distillation	3140	62	2670	53
FCC	2060	42	1650	34
Visbreaker	1080	20	1030	19
Gasoil Hydrotreater	2690	57	2500	56
Isom/Bensat	346	9.3	310	8.6
Alkylation	189	5.0	156	4.3
FCC Gasoline HDT	682	17	568	14
CCR Reformer	939	23	0	0
SR Reformer	0	0	750	19
MTBE	58	1.5	47	1.2
Desulfurisation, %				
Gasoil Hydrotreater				
Straight Run gasoil	99.0		99.5	
Cracked gasoil	95.0		95.0	
FCC Gasoline HDT	70.0		86.5	
Yields	wt% on Crude		wt% on Crude	
Input				
Brent	70.0		40.0	
Arab Lt	30.0		60.0	
Natural Gas	0.1		0.4	
Methanol	0.3		0.3	
TOTAL INPUT	100.3		100.7	
Output				
LPG	2.5		2.5	
Naphtha	7.0		6.0	
Gasoline	27.7		26.1	
Jet	9.0		6.0	
Diesel	20.1		24.4	
Gasoil	13.3		13.1	
Middle Distillate	42.4		43.5	
1%S FO	5.2		0.0	
3.5%S Export/Bunkers	7.3		13.7	
Heavy Fuel Oil	12.6		13.7	
Sulfur	0.4		0.7	
TOTAL OUTPUT	92.6		92.5	
Fuel & Loss	7.7		8.2	

IV. TECHNOLOGY REVIEW

In this section, Purvin & Gertz has reviewed the main types of process technology likely to be considered for production of ULS gasoline and diesel versus 50 ppm gasoline and diesel. The review is based on Purvin & Gertz' prior experience in both Europe and the U.S., and on discussions with process licensors, refining companies and industry organizations. There are many process options within the main categories and the discussion below does not aim to represent a complete review of all the technologies available.

Many of the technologies are developing rapidly due to the need to reduce sulfur content. In many cases, the technologies are not fully commercially proven and only a few, if any, plants have been built. The technology will inevitably develop further over the coming years. Purvin & Gertz has considered that processes at the leading edge of technology will be developed sufficiently to be commercially viable by the 2005 to 2008 time frame. However, we have not considered processes which are still currently at the very early development stage.

DESULFURIZATION PROCESSES

The two desulfurization processes considered in this study are sweetening and hydrotreating. In petroleum fractions sulfur is present in many chemical species. Sweetening is effective only against mercaptans, which are the predominant species in light gasoline. Hydrotreating is effective against all the species and is more widely used. Both processes are described below.

SWEETENING

In the sweetening process, a light naphtha or an LPG stream is first washed with amine to remove hydrogen sulfide (H_2S). The stream is then reacted with caustic, which promotes the conversion of mercaptans to disulfides. Disulfides can subsequently be extracted and removed in what is referred to as extractive sweetening.

HYDROTREATING

In the hydrotreating process, the feed is reacted with hydrogen, in the presence of a solid catalyst. The hydrogen removes sulfur by conversion to H_2S, which is subsequently separated and removed from the reacted stream. As the reaction is favored by both temperature and pressure hydrotreater reactors are typically designed and operated at 300 to $400^{o}C$ and 30 to 60 barg. The lower ends of the ranges typically apply to gasoline desulfurization, while gasoil desulfurization requires a more severe operation.

Hydrogen is provided in the form of treating gas at a purity typically around 90vol%. Hydrogen is produced by catalytic reformers or hydrogen generation units and distributed to the hydrotreaters through a refinery-wide network.

In a hydrotreating unit feed and treating gas are combined and brought to the reaction temperature and pressure, prior to entering the reactor. The reactor is a vessel preloaded with solid catalyst, which promotes the reaction. The catalyst is slowly deactivated by the continuous exposure to high temperatures and by the formation of a coke layer on its surface. Refineries have to shutdown the units periodically and regenerate or replace the catalyst.

The severity of operation of an existing unit can be increased by increasing the reaction temperature. However, there is a negative impact on the catalyst life and consequently the operating costs. The severity of operation can also be increased by increasing the catalyst volume of the unit. In this case the typical solution is to add a second reactor identical to the existing one, doubling the reactor volume. The pressure of an existing unit cannot be changed to increase its severity, because the pressure is related to material of construction and thickness of metal surfaces. If higher pressure is required, the typical solution is to install a new unit and use the existing one for a less severe service.

GASOLINE DESULFURIZATION

The main source of sulfur in gasoline produced from European refineries is FCC gasoline produced from the catalytic cracker itself. Refiners have already had to consider the treatment of FCC gasoline to meet the year 2000 150 ppm maximum sulfur content in gasoline. Further consideration of the handling and blending of this material is already being considered for production of 50 ppm sulfur content gasoline.

For a sulfur content in gasoline of below around 30 ppm, other refinery streams, which would not generally be considered a problem in the production of 50 ppm gasoline now have to be considered. As discussed in more detail below, these streams are mainly produced from processes which convert LPG streams to gasoline blending components such as alkylate and MTBE.

The main operational changes and process configuration changes likely to be considered by refiners to reduce gasoline sulfur content are discussed in turn below.

UNDERCUTTING FCC GASOLINE

The heaviest 15% of FCC gasoline may typically contain 60% of the sulfur contained in the whole FCC gasoline. Reduction of the cut point of FCC gasoline will result in a rejection of the heaviest, higher sulfur content material from the FCC gasoline stream to light cycle oil (LCO). This operational change in some cases could be made in the main FCC fractionation column, or in other cases could be made by an FCC gasoline splitter with the heavy FCC gasoline produced as a separate stream. In the first case, the heavy FCC gasoline would be simply blended with the LCO in the main fractionation column and the additional LCO would then be used for heavy fuel oil cutterstock or further processed for production of heating gasoil or diesel. In the second case, the segregated heavy FCC gasoline would most likely be used as fuel oil cutterstock to back out some higher quality material such as kerosene. As a result, this operational change results in a yield shift from gasoline to middle distillate.

We expect that most refiners will need to reject the heaviest part of the FCC gasoline from the gasoline pool to meet the 50 ppm sulfur content specification. In many cases, refiners have made adjustments to the FCC gasoline end point to meet 150 ppm. As a result, the scope for further reductions of FCC gasoline end point to meet 10 ppm are expected to be relatively limited.

FCC FEED PRETREATING

Currently around one-quarter of catalytic cracking refineries in the EU15 countries have some form of desulfurization of the feed to the FCC unit. The type of feed pretreatment can range from units designed to remove sulfur with little yield change to hydrocracking units which convert much of the feed to naphtha and middle distillate products with the remaining heavy material used for FCC feed. FCC pretreatment can improve the yields of the FCC itself as well as reducing the sulfur content of all the FCC products. However, capital investment costs are relatively high. In addition, depending on the severity of operation, FCC pretreatment can require significant hydrogen for processing and this may result in the requirement for the addition of hydrogen production facilities.

In most cases, refiners would not make the investment in FCC feed pretreatment simply to remove sulfur. If a refiner was to choose this investment option, the other benefits of FCC pretreatment such as conversion of feed to middle distillate product, reduction of sulfur dioxide in flue gas from the FCC, and the improved yields in the FCC itself are likely to be significant considerations. In most cases our expectation is that refiners will choose post-treatment of products to avoid the substantial capital costs involved with FCC pretreatment. However, in some refineries with very high sulfur content feedstocks, a combination of FCC feed pretreatment and product post-treatment may be required to meet 50 ppm or 10 ppm sulfur content.

FCC GASOLINE DESULFURIZATION

The chemical nature of FCC gasoline changes through the boiling range. This is an important consideration for selection of the desulfurization processes for FCC gasoline. In most cases, and especially when moving to ULS gasoline production, refiners will install an FCC gasoline splitter. Typically, this distillation column will split the FCC gasoline into light, medium and heavy FCC gasoline fractions. The lighter FCC gasoline components tend to be olefinic in nature while the heavy gasoline is more aromatic. The desulfurization technique employed is usually different for the lighter material than the heavier material due to the different chemical nature.

FCC Gasoline Sweetening

FCC gasoline sweetening processes are widely employed in the industry. Most applications of these processes do not remove sulfur from the FCC gasoline but convert undesirable mercaptan sulfur to less problematic disulfides. An additional step in the process can employ an extraction operation in which part of the disulfides are subsequently removed. Typically around 50% of the feed sulfur can be removed using such a process.

Since the light FCC gasoline contains the lowest sulfur content of the three gasoline cuts use of a sweetening process with extraction would be able to reduce the sulfur content of the light FCC gasoline to an acceptable level in many cases. Although the sulfur content may not be below 10 ppm, the process modification is a relatively low cost option and is likely to be one of the first options considered by refiners.

In addition, the process does not result in any other quality changes to the light FCC gasoline. Hydrotreating, as discussed below, results in saturation of the olefinic material in the light FCC gasoline. The saturation of this material reduces the octane of the hydrotreated light FCC gasoline. As a result, most refiners will try to avoid hydrotreating of light FCC gasoline.

FCC Gasoline Hydrotreating

The medium and heavy FCC gasoline streams from the FCC gasoline splitter can be hydrotreated to remove sulfur. In many cases, hydrotreating through a conventional hydrotreater of the medium FCC gasoline may be sufficient to meet 150 ppm or even 50 ppm sulfur content. Due to the presence of some olefinic material in the medium FCC gasoline, there is generally some octane loss as a result of the hydrotreating. Some refiners have employed this approach to meet the 150 ppm sulfur content gasoline specification and have recovered octane by routing the hydrotreated material to a catalytic reformer. The heavy FCC gasoline can also be hydrotreated although many refiners will consider use of this material for heavy fuel oil cutterstock or for use in heating gasoil or diesel following hydrotreating in a gasoil hydrotreating unit.

FCC gasoline hydrotreating technology is developing rapidly. There are a number of processes which claim relatively high levels of desulfurization in the 95% and above range with little or no octane loss. In some cases, the octane of the product is maintained but some gasoline yield loss results. Other processes employing catalytic distillation technology are also developing rapidly. Some plants employing these new processes are now in operation and it is our expectation that the technology will develop further in the next five years.

Absorption Processes

There are a number of processes which have recently become available which remove sulfur from gasoline streams through absorption. The use of such processes avoids the undesirable loss of octane resulting from saturation of olefins through hydrotreating. The development of these processes for removal of sulfur from gasoline to below the 10 ppm level is in the relatively early stages. During our discussions with refiners, it was indicated that although these processes were being considered, a hydrotreating based process was considered to be the most likely solution at this time.

TREATMENT OF BUTANE AND LPG DERIVED STREAMS

Butane is blended into gasoline by most refineries. The price of gasoline is almost always higher than the price of butane and refineries are able to blend a limited amount of butane into gasoline up to the vapor pressure specification.

There are a number of gasoline blending components derived from LPG feedstocks. Many catalytic cracking refineries also have alkylation units. The alkylation unit feeds butene, and sometimes propene, and produces a high quality gasoline component, alkylate. Refinery based MTBE production uses isobutene as its main feedstock.

The sulfur content of the gasoline blending components butane, alkylate and MTBE is very low but can be in the 20 to 30 ppm range. Although not a concern at the 50 ppm level, these streams need to be considered at gasoline sulfur content specifications below 30 ppm. Production of ULS gasoline of 6 to 7 ppm certainly requires that the treatment of these streams is considered. In most refineries LPG streams are sweetened using processes similar to the FCC gasoline sweetening processes described earlier. Most of the processes employed for LPG often already include some extraction of sulfur compounds. However, many refineries will be able to employ a relatively low cost improvement to this process which will enable the sulfur content of the LPG streams and the MTBE and alkylate produced from them to be reduced to around the 10 ppm level.

DIESEL DESULFURIZATION

Diesel desulfurization is currently primarily carried out using hydrotreating processes. As the sulfur content specifications of diesel and heating gasoil have reduced in Europe, the hydrotreating requirement and severity has increased. The trend is expected to continue as diesel sulfur content is reduced further.

Like gasoline, diesel is produced through blending of a number of refinery streams. Some straight run diesel blending components are produced from the distillation of crude oil, the first processing step in almost all refineries. The straight run diesel components require hydrotreating to remove sulfur but in other respects such as cetane, density and polyaromatics content are relatively good in quality although this is dependent on the crude source.

In refineries with hydrocrackers, the hydrocracker itself is a source of diesel blending component. The quality of the diesel produced from hydrocrackers is dependent on the operating conditions of the hydrocracker. Typically the diesel produced from a hydrocracker is superior in quality to straight run production and is lower in sulfur content. In many cases diesel produced from hydrocrackers would not require further treatment even to meet 10 ppm sulfur content.

The diesel blending component produced from FCC units is low in quality. Light cycle oil (LCO) is low in cetane, high density, high in polyaromatics and high in sulfur content unless the FCC feed has been pretreated (see above). As diesel specifications have tightened, most refiners have been forced to reduce the amount of LCO which can be blended into diesel. In countries with a market for heating gasoil, refiners can utilize the LCO in blending of the lower quality heating gasoil. Alternatively, refiners can use the LCO as viscosity cutter in heavy fuel oil blending. However, this requirement is reducing as heavy fuel oil demand reduces. Many refiners will therefore consider investments to upgrade LCO to diesel quality. The processes capable of upgrading LCO to diesel are generally expensive because of their relatively high operating pressure and expensive catalysts.

The removal of sulfur to very low levels in the diesel product means that all sulfur containing molecules in the diesel require treatment. Some sulfur containing species are much more difficult to remove than others. For straight run diesel components, sulfur removal from the more difficult species can be achieved by employing a different type of desulfurization catalyst. Typically Cobalt Molybdenum (CoMo) catalysts are employed for desulfurization. However, to remove the more difficult sulfur species for production of ULS diesel, Nickel Molybdenum (NiMo) catalyst is generally preferred. Use of NiMo catalyst results in higher hydrogen consumption in the hydrotreating process as some hydrogen is consumed in saturation of the aromatic species. The saturation of some aromatics species results in additional improvement in cetane quality and reduces density and polyaromatics.

The utilization of NiMo catalysts will assist with the production of ULS diesel. In addition, higher pressure units are likely to be required to produce ULS diesel in many cases. Prior to the introduction of the 500 ppm sulfur content for diesel in 1996, diesel hydrotreaters operating at below 30 bar pressure were widely used. The introduction of the 500 ppm specification resulted in replacement of some of these units with higher pressure units particularly in refineries processing higher sulfur content crudes. However, many low pressure units were modified to meet the 500 ppm specification and further plant modifications and management of the streams to be treated have resulted in continued use of these units for 350 ppm diesel production. However, it is unlikely that many of these low pressure units would be capable of 50 ppm diesel production even with a low sulfur crude slate. Most refineries are likely to require at least one unit capable of operating at higher pressure (50-60 bar) to meet the 50 ppm specification.

The amount of LCO hydrotreated will also be an important factor in determination of the required operating pressure of the hydrotreater. Refineries that wish to upgrade significant quantities of LCO to diesel are likely to need to invest in high pressure units operating at 90-100 bar. As diesel sulfur content is driven lower the requirement for these high pressure units will increase.

In summary, the technology to achieve production of diesel with sulfur content below 10 ppm is generally considered to be available now. In areas with a local heating oil market and economic access to low sulfur crude, a refinery may only need to add more hydrotreating catalyst, change to a more active catalyst and carefully select hydrotreater feedstocks in order to achieve 10 ppm diesel sulfur content. At the other end of the range, refiners processing higher sulfur content crudes and processing LCO may need to move to high pressure hydrotreating and associated hydrogen purification and production facilities. The range of investments for individual refineries is likely to be very wide as a result and will also be dependent on the design of the hydrotreater currently in operation.

V. REVIEW OF CASES

This section discusses each of the cases studied to develop the range of costs associated with the production of ULS fuels. Purvin & Gertz used its proprietary linear program (LP) model to develop refinery yields for each case. For each case a description of the modeling philosophy and the main assumptions are given. As discussed in Section III, the simulations have been developed to maintain constant yields, as far as practical. Yield tables for the three families of cases are attached at the end of the section in Table V-1 to V-3. Capital cost estimates were based on Purvin & Gertz' in-house databases and discussions with licensors and refiners. The capital costs should be considered as curve-type estimates and include an allowance for offsites, contingency and owners costs. Variable cost estimates were based on Purvin & Gertz' in-house data and discussions with licensors and refiners. Fixed costs include maintenance, manpower, rates, insurance, taxes and other fixed costs and were developed using Purvin & Gertz' operating cost models.

NORTHWEST EUROPE CATALYTIC CRACKING REFINERY

The following three cases have been studied for the Northwest Europe catalytic cracking yardstick refinery:

- production of 10 ppm sulfur gasoline
- production of 10 ppm sulfur diesel
- production of both 10 ppm sulfur gasoline and diesel.

PRODUCTION OF 10 PPM SULFUR GASOLINE

The table below shows the sulfur content of gasoline blending components in the Base Case and ULS case. The maximum sulfur content specified in the simulation was 45 ppm, for the Base Case, as refineries would target a sulfur content lower than the specification, in order to have operational flexibility.

GASOLINE PRODUCTION - NORTHWEST EUROPE

(Sulfur content of blending components, ppm)

	Base Case	ULS	Process Change
Butane	20	8	Improvement of sweetening operation
Light FCC gasoline	20	10	Extractive sweetening
Medium FCC gasoline	140	11	Higher severity hydrotreating
Alkylate	25	10	Improvement of sweetening operation
MTBE	25	10	Improvement of sweetening operation

The following three observations can be made on the basis of the table above:

- approximately 90% of the sulfur is contributed by the FCC gasoline in the Base Case;
- if the specification is lowered to 10ppm, butane, MTBE and alkylate would no longer be sulfur diluents
- in order to achieve the 45 ppm specification all of the heavy FCC gasoline is routed to the distillate pool.

It has been assumed that, if a specification of 10ppm were introduced, refineries would target a value of 7ppm in their design and operation. Amongst the operational changes and process configurations discussed in Section IV, the improvements shown above are expected to be the typical approach of catalytic cracking refineries to achieve the specification:

Any increase in hydrotreating severity will be associated with some octane loss. As sweetening units involve very limited capital costs, the first two steps are expected to be considered in order to minimize the requirement for increasing the FCC naphtha hydrotreating severity, thereby minimizing octane losses.

In order to meet the specification, the medium FCC gasoline desulfurization severity had to be increased to 97.5%. It was assumed that refineries would accomplish this by maintaining constant liquid yields from the unit and accepting some octane loss. This approach maintains the yields as close to constant as possible and minimizes the distortion of the analysis introduced by major yield shifts. Refineries are in fact expected to implement site specific trade-offs between yields loss and octane loss. The loss of octane has been assumed to be 1.5 RONC/1.5 MONC. This figure represents a reasonable assumption obtained from published literature and discussions with licensors and refiners for technology specifically developed for the selective hydrotreating of FCC gasoline minimizing octane loss. The octane lost in a conventional hydrotreater would certainly be much higher than the value assumed.

The loss of octane must be compensated by an increase in reforming severity, and associated loss of gasoline yield. The higher reforming severity also produced a marginal increase in LPG production. Fuel oil production also increased as by-product fuel gas replaced fuel oil in the refinery fuels pool.

Capital Expenditure

The capital expenditure in this case is mainly associated with the installation of a grassroots light FCC gasoline extractive sweetening process. In addition, some investment will be required to improve the operation of the existing butene sweetening units and to upgrade the FCC gasoline hydrotreater to the higher severity operation. The overall capital expenditure has been estimated at around €5 million.

Operating Costs

The following additional operating costs have been recognized.

- yield deterioration suffered because of the higher reforming severity;
- additional variable costs associated with the higher reforming severity (fuel and catalyst);
- additional variable costs associated with the higher FCC gasoline hydrotreating severity;
- additional variable costs introduced by the new sweetening unit and the upgrade of the existing ones;
- increase in fixed costs due to the installation of additional assets;

The increase in operating costs was estimated at €1.3 million per year.

Cost Variance

Some catalytic cracking refineries will incur costs higher than estimated above. Some refineries, such as those processing low sulfur content crudes, may be in a position to meet the 50 ppm specification by implementing a different FCC gasoline splitting philosophy. The FCC gasoline can be undercut, thereby maximizing the routing of heavy FCC gasoline to middle distillate and consequently maximizing the sulfur routed away from the gasoline pool. The medium FCC gasoline has a relatively low octane number and can be partially routed to catalytic reforming. The remaining part of FCC gasoline may be low enough in sulfur to be blended to 50 ppm, without additional treatment. If a specification of 10 ppm is introduced, these refineries may need to install dedicated FCC gasoline hydrotreating capacity to process all or the remaining medium FCC gasoline.

Another specific situation involving higher costs may be generated by the structure of the gasoline pool. Purvin & Gertz' yardstick refinery includes a CCR reformer, an alkylation unit and a MTBE unit and can produce relatively high octane gasoline. Refineries short of octane or constrained by the aromatic content of the pool may not be able to compensate for the octane lost in the FCC gasoline hydrotreater. A number of refineries may be forced into reformer and isomerization revamps. Alternatively these refineries may opt for additional MTBE imports and the associated increase in feedstock cost.

PRODUCTION OF 10 PPM SULFUR DIESEL

The diesel pool of the Northwest Europe yardstick refinery in the Base Case is composed of straight run middle distillates desulfurized to 45 ppm as shown below. All Cracked Distillate, including LCO is routed to heating oil.

GASOIL POOL COMPOSITION AND SULFUR CONTENT - NORTHWEST EUROPE
(wt% and ppm of Sulfur for Base Case and 10ppm Diesel)

	Pool (wt%)		Sulfur (ppm)		Remarks
	Diesel	Heating Oil	Base	10ppm	
Light Kerosene	0	25	870	870	not hydrotreated
Hydrotreated Low Sulfur Gasoil	70	0	30	7	hydrotreating severity increased
Hydrotreated High Sulfur Gasoil	2	25	190	45	hydrotreating severity increased
Hydrotreated Cracked Distillate	0	50	750	750	heating oil only
Hydrotreated Heavy Kerosene	28	0	35	7	hydrotreating severity increased

As discussed in Section IV, NiMo catalysts are better suited to the deep desulfurization required to meet the 10 ppm specification. The use of NiMo catalyst results in higher hydrogen consumption. The extra consumption has been assumed to be 20% based on discussions with licensors and catalyst companies. A side-effect of this desulfurization route will be a reduction in density and an increase in cetane number of the desulfurized stream. The impact on refinery yields is minimal and limited to the provision of the extra hydrogen required.

As in the gasoline case, the costs sustained by refineries will be very site specific, again dependent on the existing facilities and the modifications undertaken to meet the 50 ppm specification. Two cases have been considered representative of the two ends of the range. At the lower end of the range is a refinery utilizing a medium pressure hydrotreater to produce 50 ppm diesel in 2005. This is in line with Purvin & Gertz' yardstick refinery and the hydrotreater is likely to be designed with a pressure in the region of 50 to 60 bar and is expected to offer the possibility of cost effective revamping if the specification is reduced to 10 ppm.

At the higher end of the range is a refinery with low pressure hydrotreaters, hydrotreaters already revamped to meet the 50 ppm specification, processing higher sulfur content crudes or needing to upgrade LCO to diesel. These refineries will have to meet the 10 ppm specification by installing grassroots diesel hydrotreaters of higher pressure in the 90-100 bar range.

Capital Expenditure

The yardstick refinery uses approximately 45,000 Barrels Per Stream Day (BPSD) of straight run gasoil desulfurization capacity and 13,000 BPSD of cracked distillates desulfurization capacity. Approximately 36,000 BPSD is committed to diesel desulfurization. Grassroots units coming on stream in 2005 and designed for 50 ppm diesel, are expected to be able to meet the 10 ppm specification by adding a second reactor and approximately doubling the catalyst employed. Some increase in severity may also be required with reduction of run length and increase in operating costs.

We additionally expect the need to provide more hydrogen and the incentive to improve the hydrogen management in order to increase the hydrogen partial pressure in the reactors.

The risk of higher unreliability due to the new specification has also been recognized. The new specification will increase the risk of product contamination and the need of downgrading finished diesel to heating oil. We expect that refineries will have to install some extra capacity in addition to that calculated by the model and this has been allowed for.

On this basis the overall capital expenditure has been estimated at approximately €30 million.

If the 50 ppm specification cannot be met by revamping existing units, a reduction to 10 ppm will necessarily involve the installation of some grassroots capacity. In this case, it has been assumed that limited revamp of existing units is possible and some further improvement of the existing operation can be implemented to minimize the size of the new unit. The existing units would not necessarily be made obsolete by the change in specification and would be utilized to minimize the overall investments. For this case the overall capital expenditure has been estimated around €120 million.

Operating Costs

The following additional operating costs have been recognized:

- variable costs associated with the higher severity of operation;
- catalyst costs associated with the increase in catalyst volume;
- variable costs associated with the downgrade of diesel to heating oil;
- variable cost associated with hydrogen generation;
- fixed costs due to the installation of new plant.

Additionally, extra manpower will be required if a grassroots unit is needed.

The increase in operating costs was estimated at €1.4 million per year if no grassroots unit is needed and €4.7 million per year if a grassroots unit is needed.

PRODUCTION OF 10 PPM GASOLINE AND SULFUR

The simultaneous production of 10 ppm sulfur gasoline and diesel was modeled. Only minor synergies or interferences were found. The hydrogen produced by catalytic reformers will be beneficial to the increased desulfurization requirements of ultra low sulfur diesel. The tendency to lower the cut point of FCC gasoline will marginally modify the composition of the middle distillate pool.

Neither of these effects are significant and there is no synergy in production of the two fuels.

MEDITERRANEAN CATALYTIC CRACKING REFINERY

The following cases were studied for the Mediterranean catalytic cracking refinery:

- production of 10 ppm sulfur gasoline
- production of 10 ppm sulfur diesel
- production of both 10 ppm sulfur gasoline and diesel
- production of 10 ppm sulfur gasoline by pretreating FCC feed.

PRODUCTION OF 10 PPM GASOLINE

The gasoline pool of the Mediterranean yardstick refinery and the sulfur content of individual components in the Base Case and ULS case is shown in the table below.

GASOLINE PRODUCTION - MEDITERRANEAN EUROPE
(Sulfur content of blending components, ppm)

	Base Case	ULS	Process Change
Butane	20	8	Improvement of sweetening operation
Light FCC gasoline	31	15	Extractive sweetening
Medium FCC gasoline	125	10	Higher severity hydrotreating
Alkylate	25	10	Improvement of sweetening operation
MTBE	25	10	Improvement of sweetening operation

The pool composition in the Base Case is very similar to the Northwest Europe refinery. The FCC gasoline must be desulfurized to approximately 125 ppm instead of 140ppm to produce 50 ppm gasoline. The higher proportion of sour crudes processed, means that 85% of the sulfur must be removed from the medium FCC gasoline compared to 70% in the Northwest Europe case.

As in the Northwest Europe case extractive, sweetening units have been assumed capable of reducing the sulfur content of MTBE and alkylate to 10 ppm in the ULS case. A lower value of 8 ppm has been assumed for butane due to dilution from sulfur free butane produced by catalytic reformers.

It has also been assumed that the light FCC gasoline can be sweetened with a sulfur reduction of 50%. The higher sulfur content crude slate required a FCC gasoline desulfurization rate of 98.5%. It has been assumed that the increase in desulfurization rate could be achieved at the expense of a 1.7 RONC/1.7 MONC octane loss, if yields were maintained. A slightly higher octane loss than assumed for the Northwest Europe case was assumed in recognition of the fact that limited experience exists at very high desulfurization rate.

The loss of octane is compensated by an increase in reforming severity of approximately 2 RONC.

Capital Expenditure

The capital expenditure has been estimated using the same philosophy as the Northwest Europe refinery. The estimate is around €5 million.

Operating Costs

Similar operating cost changes to the Northwest Europe refinery are expected. The different crude slate and the different size of the units made the estimate slightly different. The increase in operating cost has been estimated at €1.5 million per year.

Cost Variance

The very high FCC gasoline desulfurization rate required to process sour crudes may require some refineries investing in a combination of FCC feed pretreater and FCC gasoline post-treating.

Our alternative case assumes a low severity FCC feed pretreater installed to process only the vacuum gasoil distilled from sour crudes. The refinery yields were maintained by adjusting the FCC gasoline final boiling point as required to compensate for the gasoline shortage due to the lower availability of FCC feed. The medium FCC gasoline desulfurization rate required has been estimated at 96.5%. The capital expenditure of such a project is expected to be in the region of €90 million.

PRODUCTION OF 10 PPM SULFUR DIESEL

As in the Northwest Europe case it has been assumed that the diesel pool consists of hydrotreated straight run middle distillate and LCO will be used exclusively in the heating oil pool or as fuel oil cutter stock. The analysis has been conducted with the same criteria as the Northwest Europe case.

GASOIL POOL COMPOSITION AND SULFUR CONTENT - MEDITERRANEAN EUROPE

(wt% and ppm of Sulfur for Base Case and 10ppm Diesel)

	Pool (wt%)		Sulfur (ppm)		Remarks
	Diesel	Heating Oil	Base	10ppm	
Light Kerosene	0	23	1400	1400	not hydrotreated
Hydrotreated Low Sulfur Gasoil	33	0	15	5	hydrotreating severity increased
Hydrotreated High Sulfur Gasoil	24	33	95	30	hydrotreating severity increased
Hydrotreated Cracked Distillate	0	44	1120	1120	heating oil only
Hydrotreated Heavy Kerosene	43	0	40	2	hydrotreating severity increased

Capital Expenditures

The yardstick refinery uses approximately 45,000 BPSD of straight run gasoil desulfurization capacity and 11,000 BPSD of cracked distillates desulfurization capacity. Approximately 37,000 BPSD is committed to diesel desulfurization. This situation is very similar to the Northwest Europe case, leading to an overall investment cost estimate of approximately €30 million, based on revamp of an existing unit.

Operating Costs

The increase in operating costs has been estimated using the same criteria of the Northwest Europe refinery. The estimated cost is €1.5 million per year for the revamp case.

Cost Variance

Mediterranean refineries generally process higher sulfur content crude slates than refineries in Northern Europe. In addition, in many countries in Southern Europe the proportion of diesel produced from the diesel/gasoil mix is much higher. As a result, more refineries in the South are likely to require investment in new higher pressure hydrotreaters. We have estimated costs for such an investment of around €120 million.

PARTIAL INTRODUCTION OF ULS GASOLINE/DIESEL

HYDROSKIMMING REFINERY

A hydroskimming refinery configuration was considered for the assessment of the cost implications of limited introduction of ULS gasoline and diesel. It was assumed that 25% of the market demand for gasoline and diesel would be ULS and could be produced from hydroskimming refineries. Hydroskimming refineries are expected to face problems in meeting the specification of 35 vol% maximum aromatic content being introduced in 2005. Hydroskimmers will have an incentive to import FCC gasoline to dilute aromatics, in the gasoline pool. Since considering this possibility would distort the analysis, this case has been studied on the basis of a refinery operating with reliance solely on the import of MTBE. Other high octane/low aromatic diluents would be acceptable alternatives to MTBE.

The gasoline pool for the hydroskimmer is shown in the table below. The gasoline produced meets the aromatic specification and is very low in sulfur.

GASOLINE POOL COMPOSITION
(Base Case Hydroskimming)

	wt%	S(ppm)
Butane	1	20
Isomerate	35	0
Reformate	58	0
MTBE	6	25
Total	100	2

Such a refinery will be able to supply ULS gasoline without investment.

The Base Case hydroskimming refinery uses approximately 49,000 BPSD of desulfurization capacity to produce 50 ppm diesel. An increase in hydrotreating severity is needed to produce ULS diesel.

The same criteria have been used to estimate investment costs and operating costs. The capital costs for ULS diesel production are expected to be in the region of €30 million, for a revamp case. The model is showing a marginal hydrogen imbalance, resulting in the need for some hydrogen generation. The cost estimate assumes that hydrogen can be made available by cost effective improvement of the hydrogen system but some refineries will have to install hydrogen generation capacity.

The operating costs have been estimated to be around €1 million per year.

NORTHWEST EUROPE CATALYTIC CRACKING

One additional case has been modeled to study the partial introduction of ULS fuels covering 25% of the market. This case considers a catalytic cracking refinery configuration. Since the catalytic cracking refinery is actually a combination of hydroskimming and catalytic cracking, this case is a more reliable indicator of the overall cost to the industry of the partial introduction of ULS fuels.

The partial introduction of gasoline gives some scope for blending optimization and was studied by LP modeling. As expected, it was found that costs are less than proportional to the rate of introduction. If 25% of the gasoline is produced to a 10 ppm maximum sulfur specification, the only investments likely to be needed are the revamps of the LPG sweetening and the installation of a light FCC gasoline extractive sweetening unit. The severity of the FCC gasoline hydrotreater had to be increased slightly from 70% desulfurization to 73% to remove some extra sulfur. The impact of this change on the octane is expected to be negligible. Refineries will also have to segregate blending components, as the possibility of having such a limited investment relies on different blending recipes of the two grades of gasoline. MTBE produced in the refinery is preferentially blended into the 10ppm gasoline pool but the overall MTBE content of the gasoline pool is unchanged from the Base Case.

The table below shows the blending composition and the sulfur content of the components for the two gasolines.

GASOLINE POOL COMPOSITION - PARTIAL INTRODUCTION OF ULS GASOLINE

(Sulfur content of components and pool composition by grade)

	Sulfur (ppm)	50ppm pool (wt%)	10ppm pool (wt%)	Process Change
Butane	8	4	2	Sweetening improvement
Light FCC Gasoline	10	0	32	Extractive sweetening
Medium FCC Gasoline	120	38	0	
Isomerate	0	15	9	
Reformate	0	32	49	
Alkylate	10	10	3	Extractive sweetening
MTBE	10	1	5	Extractive sweetening

In the case of diesel, refineries are expected to handle the production by running hydrotreaters in blocked operation, or, where new hydrotreaters are required, to have the new unit dedicated to the 10 ppm grade. The conclusion is that the new capacity required is expected to be approximately proportional to the rate of introduction of the new grade. An initial deferral of costs is possible because we expect the refineries able to supply ULS diesel more cost effectively to be the first to enter in the market.

TABLE V - 1
YIELDS AND CAPACITY UTILIZATION
NORTHWEST EUROPE CATALYTIC CRACKING

	Base Case		Gasoline		Diesel		Gasoline and Diesel		Partial Introduction	
Unit Capacities	kt/year	kb/sd	kt/year	kb/sd	kt/year	kb/sd	kt/year	kb/sd	kt/year	kb/sd
Crude Distillation	8160	180	8160	180	8160	180	8160	180	8160	180
Vacuum Distillation	3140	62	3140	62	3140	62	3140	62	3140	62
FCC	2060	42	2060	42	2060	42	2060	42	2060	42
Visbreaker	1080	20	1080	20	1080	20	1080	20	1080	20
Distillates Hydrotreaters	2690	57	2610	56	2820	60	2810	60	2780	59
Isomerisation	346	9.3	347	9.4	346	9.3	347	9.3	346	9.4
Alkylation	189	5.0	192	5.1	189	5.0	192	5.1	189	5.0
FCC Gasoline HDT	682	17	684	17	682	17	693	17	688	17
CCR Reformer	939	23	939	23	939	23	939	23	939	23
SR Reformer	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
MTBE	58	1.5	58	1.5	58	1.5	58	1.5	58	1.5
Desulfurisation, %										
Gasoil Hydrotreater										
Straight Run gasoil	99.0		99.5		99.8		99.8		99.0	
Cracked gasoil	95.0		95.0		95.0		95.0		95.0	
FCC Gasoline HDT	70.0		97.5		70.0		96.5		73.0	
Yields	wt% on Crude		wt% on Crude		wt% on Crude		wt% on Crude		wt% on Crude	
Input										
Brent	70.0		70.0		70.0		70.0		70.0	
Arab Lt	30.0		30.0		30.0		30.0		30.0	
Natural Gas	0.1		0.1		0.2		0.2		0.1	
Methanol	0.3		0.3		0.3		0.3		0.3	
TOTAL INPUT	100.3		100.3		100.3		100.3		100.3	
Output										
LPG	2.5		2.6		2.5		2.6		2.5	
Naphtha	7.0		7.0		7.0		7.0		7.0	
Gasoline	27.7		27.5		27.7		27.5		27.7	
Jet	9.0		9.0		9.0		9.0		9.0	
Diesel	20.1		20.1		20.1		20.1		20.1	
Gasoil	13.3		13.3		13.4		13.4		13.3	
Middle Distillate	42.4		42.4		42.5		42.5		42.4	
1%S FO	5.2		5.3		5.2		5.3		5.2	
3.5%S Export/Bunkers	7.3		7.4		7.3		7.3		7.3	
Heavy Fuel Oil	12.6		12.6		12.5		12.6		12.6	
Sulfur	0.4		0.4		0.4		0.4		0.4	
TOTAL OUTPUT	92.6		92.6		92.6		92.6		92.6	
Fuel & Loss	7.7		7.7		7.6		7.7		7.7	

TABLE V - 2
YIELDS AND CAPACITY UTILIZATION
MEDITERRANEAN CATALYTIC CRACKING

	Base Case		Gasoline		Diesel		Gasoline and Diesel		FCC Feed Pretreat	
Unit Capacities	kt/year	kb/sd	kt/year	kb/sd	kt/year	kb/sd	kt/year	kb/sd	kt/year	kb/sd
Crude Distillation	6670	150	6670	150	6670	150	6670	150	6670	150
Vacuum Distillation	2670	53	2670	53	2670	53	2670	53	2670	53
FCC	1650	34	1650	34	1650	34	1650	34	1560	32
Visbreaker	1030	19	1030	19	1030	19	1030	19	1020	19
Distillates Hydrotreaters	2500	56	2500	55	2710	60	2710	60	2320	51
Isomerisation	310	8.6	304	8.4	310	8.6	304	8.4	308	8.5
Alkylation	156	4.0	160	4.0	156	4.0	160	4.0	160	4.0
FCC Gasoline HDT	568	14	573	15	574	15	573	15	577	15
MTBE	47	1.2	47	1.2	47	1.2	47	1.2	43	1.1
Desulfurisation, %										
Gasoil Hydrotreater										
Straight Run gasoil	99.5		99.5		99.9		99.9		99.5	
Cracked gasoil	95.0		95.0		95.0		95.0		95.0	
FCC Gasoline HDT	86.5		98.5		86.3		98.5		96.5	
Yields	wt% on Crude		wt% on Crude		wt% on Crude		wt% on Crude		wt% on Crude	
Input										
Brent	40.0		40.0		40.0		40.0		40.0	
Arab Lt	60.0		60.0		60.0		60.0		60.0	
Natural Gas	0.4		0.4		0.6		0.5		0.7	
Methanol	0.3		0.3		0.3		0.3		0.2	
TOTAL INPUT	100.7		100.7		100.8		100.8		100.9	
Output										
LPG	2.5		2.7		2.5		2.7		2.4	
Naphtha	6.0		6.0		6.0		6.0		6.0	
Gasoline	26.1		25.8		26.1		25.8		26.1	
Jet	6.0		6.0		6.0		6.0		6.0	
Diesel	24.4		24.4		24.4		24.4		24.7	
Gasoil	13.1		13.1		13.1		13.1		13.3	
Middle Distillate	43.5		43.5		43.5		43.5		44.0	
1%S FO	0.0		0.0		0.0		0.0		0.0	
3.5%S Export/Bunkers	13.7		13.8		13.8		13.8		13.6	
Heavy Fuel Oil	13.7		13.8		13.8		13.8		13.6	
Sulfur	0.7		0.7		0.7		0.7		0.7	
TOTAL OUTPUT	92.5		92.5		92.6		92.5		92.8	
Fuel & Loss	8.2		8.2		8.2		8.2		8.1	

TABLE V - 3
YIELDS AND CAPACITY UTILIZATION
NORTHWEST EUROPE HYDROSKIMMING

	Base Case		Diesel	
Unit Capacities	kt/year	kb/sd	kt/year	kb/sd
Crude Distillation	8160	180	8160	180
Vacuum Distillation	0	0	0	0
FCC	0	0	0	0
Visbreaker	0	0	0	0
Distillates Hydrotreater	2260	49	2350	51
Isomerisation	393	10.7	393	10.7
Alkylation	0	0.0	0	0.0
FCC Gasoline HDT	0	0	0	0
CCR Reformer	682	0	682	0
SR Reformer	0	0.0	0	0.0
MTBE	0	15.1	0	15.1
Desulfurisation, %				
Gasoil Hydrotreater				
Straight Run gasoil	98.5		99.8	
Cracked gasoil	95.0		95.0	
FCC Gasoline HDT	80.0		80.0	
Yields	wt% on Crude		wt% on Crude	
Input				
Brent	70.0		70.0	
Arab Lt	30.0		30.0	
Natural Gas	0.0		0.1	
Methanol	0.0		0.0	
TOTAL INPUT	100.3		100.3	
Output				
LPG	2.3		2.3	
Naphtha	7.0		7.0	
Gasoline	12.9		12.9	
Jet	9.0		9.0	
Diesel	22.2		22.2	
Gasoil	7.4		7.4	
Middle Distillate	38.6		38.6	
1%S FO	25.9		25.9	
3.5%S Export/Bunkers	9.2		9.2	
Heavy Fuel Oil	1.7		1.7	
Sulfur	0.2		0.2	
TOTAL OUTPUT	95.9		95.9	
Fuel & Loss	4.3		4.3	

VI. ECONOMIC RESULTS

Based on the cases described in Section V, Purvin & Gertz has developed a range of investment costs for ULS gasoline and diesel production for Northern Europe and Southern Europe. The costs have been calculated per tonne of gasoline or diesel produced. Three approaches have been used to express the costs. One is in line with the approach proposed by the European Commission which involves a projection of capital and operating costs discounted back to year 2007. The second approach uses the Auto Oil 1 method of adding capital costs to 9.75 times operating costs. The third approach uses Purvin & Gertz' standard methodology for estimation of the likely price premium for new specification products compared to existing specifications. We feel Purvin & Gertz' approach provides a more robust indication of the impact of the introduction of ULS fuels versus 50 ppm fuels. The concept of only discounting costs with no positive revenue stream results in the anomaly of higher discount rates giving a lower Net Present Value (NPV) of the future cash flow.

SUMMARY OF RESULTS

The costs per tonne of gasoline and diesel for production of 10 ppm sulfur content fuel compared to 50 ppm are summarized in the table below. The estimated price premium for 10 ppm fuels versus 50 ppm is also shown.

ECONOMIC RESULTS

	Northern Europe		Southern Europe	
	Gasoline	Diesel	Gasoline	Diesel
Cost, €/tonne				
@ 4% Discount Rate	1-2	3-5	2-4	5-7
@ 7% Discount Rate	1-2	3-5	2-4	5-7
Auto Oil 1 Approach (1)	1	3-5	2-4	5-7
Price Premium €/tonne	1-3	4-7	2-4	7-10
Cost Cents per litre				
@ 4% Discount Rate	0.1-0.2	0.3-0.4	0.2-0.3	0.4-0.6
@ 7% Discount Rate	0.1-0.2	0.3-0.4	0.2-0.3	0.4-0.6
Auto Oil 1 Approach (1)	0.1	0.3-0.4	0.2-0.3	0.4-0.6
Price Premium c/litre	0.1-0.3	0.3-0.6	0.2-0.3	0.6-0.9

Note : (1) (Capex + 9.75*Annual Opex)/(15 years production)

The results are shown in Table VI-1 and discussed in more detail below.

GASOLINE

NORTHERN EUROPE

A range of likely investments for a European catalytic cracking refinery in Northern Europe has been estimated. Purvin & Gertz' yardstick catalytic cracking refinery in Northern Europe requires investments similar to that described in Section V. Investments are required to modify the light FCC gasoline sweetening unit to extract additional sulfur, the treatment of LPG and gasoline blend stocks derived from LPG to remove additional sulfur and more severe hydrotreating of the medium FCC gasoline. Since the Base Case producing 50 ppm gasoline already assumes the use of an FCC gasoline hydrotreater unit, the additional costs involved in moving to ULS gasoline production are relatively small. The investment cost is estimated to be around €5 million. The combination of yield deterioration and additional operating costs is estimated to be close to €1.3 million per year. The NPV of these additional costs expressed per tonne of gasoline production were estimated to be around €1/tonne.

Purvin & Gertz has also considered a case in which the refinery has not made the investment in a dedicated FCC gasoline hydrotreater to meet 50 ppm sulfur gasoline. As discussed in Section IV, some refiners are removing sulfur from gasoline by treating the medium FCC gasoline through their existing naphtha hydrotreater and catalytic reformer. For refiners able to meet 50 ppm sulfur taking this approach it is likely that the further reduction to 10 ppm gasoline would result in the requirement for a dedicated FCC gasoline hydrotreater. In this case the capital cost is expected to increase to around €25 million and with an associated increase in operating costs. The cost per tonne of gasoline is estimated to be nearly €2/tonne in this case.

Purvin & Gertz has also used its own approach to estimating the likely price premium for ULS gasoline compared to 50 ppm gasoline. Purvin & Gertz has used this approach successfully on previous occasions to estimate the price premium for new specification products. The approach considers the combination of increased operating costs and yield penalty involved with moving to the higher specification and considers a range of capital recovery factors (CRF) as an indicator of financial return on the capital investment made. The CRF is a simple measurement of return on investment which is expressed as a percentage of the total capital costs. Prior analysis has indicated that a CRF in the 20 to 25% range results in an after-tax real internal rate of return in the 10 to 12% range. Based on previous analysis when specifications have changed, we have observed that refineries able to make a relatively low cost revamp or modification to their refineries to meet new specifications can achieve a CRF of around 20%. However, refiners unable to carry out these low cost investments and required to make high cost modifications involving grassroot process units will achieve CRF of under 10%. As a result, for ULS gasoline in Northern Europe we would expect the price premium versus 50 ppm gasoline to be in the €1 to €3/tonne range.

SOUTHERN EUROPE

A similar approach has been used for consideration of costs in Southern Europe. Similar modifications for treatment of the LPG and LPG derived gasoline streams and the light FCC gasoline are employed in the case of Southern Europe. However, due to the higher sulfur content of the feedstock employed in Southern Europe the severity of the hydrotreating of the FCC gasoline required is somewhat greater. Total costs are estimated to be close to the Northern Europe level at around €1/tonne.

Due to the processing of the higher sulfur content crude slate in Southern Europe, it is likely that many refineries will need to consider the pre-treatment of FCC feedstock as well as the investments in post-treatment processes. The investment in FCC pre-treatment increases the capital costs considerably. We have assumed a FCC pre-treater designed primarily for desulfurization with little shift in yields. This is to minimize the effect of the yield change on the economics. In this case the cost is calculated to be equivalent to nearly €4/tonne of gasoline.

It is expected that refiners needing to make investments in FCC pre-treatment and post-treating facilities are expected to achieve a relatively low capital recovery factor on that investment. The refiners able to achieve ULS gasoline specifications with a low cost approach will achieve significantly higher CRF. As a result, we expect the premium for ULS gasoline versus 50 ppm gasoline in Southern Europe to be in the €2 to €4/tonne range.

DIESEL

NORTHERN EUROPE

For our yardstick catalytic cracking refinery in Northwest Europe we expect that ULS diesel specifications would be able to be achieved through revamp of the existing medium pressure hydrotreater to increase severity and capacity. Some investment in hydrogen facilities is also expected. Based on these assumptions the combined capital costs, operating costs and yield shift is equivalent to around €2/tonne of diesel.

There will be some catalytic cracking refineries in Northern Europe not able to produce ULS diesel at such a low cost. Refineries processing a higher sulfur content crude slate, producing a lower proportion of heating gasoil and refiners still operating low pressure hydrotreaters would be in this category. It was assumed that these refineries would need to make an investment in a grassroots higher pressure hydrotreater for processing of the more difficult streams to desulfurize. In this case the costs increase to around €7/tonne of diesel.

Refineries able to take the low cost approach are likely to be able to achieve a relatively higher return on their capital investment while refineries requiring the high pressure hydrotreating investment are expected to achieve a relatively low rate of return. As a result, we expect the price premium for ULS diesel to be in the €4 to €7/tonne range compared to 50 ppm diesel.

SOUTHERN EUROPE

Similar considerations apply in Southern Europe. However, there are likely to be more refineries unable to produce ULS diesel using a relatively low cost approach and a higher proportion of high pressure hydrotreating units are likely to be required. The costs for the low cost and high cost cases are similar to those in Northern Europe but a higher proportion of refiners in Southern Europe are likely to need to take the higher cost approach.

The price premium for ULS diesel versus 50 ppm diesel is expected to be towards the higher end of the range in Southern Europe. As a result, we expect the price premium in Southern Europe to be in the €7 to €10/tonne range as a higher proportion of refineries will be required to invest in high pressure hydrotreating.

COMMENTS ON THE ECONOMIC RESULTS

Purvin & Gertz was requested to comment on a number of aspects related to the study but not directly addressed in this study. These comments are provided below.

Other Quality Effects

Based on discussions with licensors and the results from Purvin & Gertz' LP models, the effects on other qualities of gasoline and diesel using the processes described above are relatively minor. For gasoline, modifications to the FCC gasoline and LPG sweetening processes are based on extraction and as a result do not change the quality of the product streams other than their sulfur content. Employment of FCC gasoline hydrotreating may result in some reduction in olefins content in the blended gasoline produced. However, since hydrotreating of FCC gasoline is expected to be employed to produce 50 ppm gasoline the additional reduction in olefins is insignificant.

For diesel, the employment of NiMo catalyst will result in some saturation of the aromatic species in diesel. The improvement based on discussions with licensors was built into our refinery LP model. The overall effect on diesel quality was an improvement in cetane index of around 0.8, and an improvement in density of around 0.004 kg/litre. There would also be expected to be some slight improvement in polyaromatics but this was not modeled in our refinery LP. Although slight improvement in these properties is anticipated the magnitude of the improvement is relatively small and our assessment is that the improvement in overall diesel quality as a result of these side effects is not significant.

Supply Implications

The approach used in this study is to maintain refinery yields for most of the major refined products by making investments. The resultant shifts in yields for the ULS gasoline and diesel cases versus the base case are relatively minor as a result.

In practice, as discussed in Section III, many refineries will accept some degradation in yields to avoid or reduce the level of capital investment required. For gasoline, overall yields may be reduced and may result in additional production of naphtha and middle distillates. Since gasoline is currently in excess of requirements in Europe and gasoline demand is expected to decline in the future, the reduction in gasoline yield is not a major concern.

In the case of diesel, many refineries are likely to only treat the easier diesel blending components to meet 50 ppm and 10 ppm sulfur content in diesel. Directionally this is likely to reduce diesel supply and increase heating gasoil and possibly heavy fuel oil supply. Since demand for diesel in Europe is expected to grow and demand for heating gasoil and heavy fuel oil is expected to decline, the yield shift from diesel to lower quality products is a concern with respect to the European supply/demand balance. Imports can provide an additional source of diesel supply but with the continued improvements in European diesel quality the sources of potential diesel imports are extremely limited at the 50 ppm level and would essentially disappear at the 10 ppm sulfur level.

Most likely the reduction in diesel supply will result in a strengthening of diesel prices relative to other products. The degree to which diesel prices increase will ultimately be dependent on the level of financial return on investment which refiners are prepared to accept before making the necessary investments to redress the diesel supply/demand balance. The changeover to year 2000 diesel specifications has resulted in European refiners using more kerosene for diesel blending to meet the new specifications. Since the kerosene supply/demand balance in Europe is relatively tight some of these additional volumes have come from imports of kerosene from the Middle East. However, with a very low diesel sulfur content of 50 ppm or 10 ppm this kerosene import would need to be severely hydrotreated to meet the new specification and this may result in this alternative source of supply becoming uneconomic.

The supply/demand balance for diesel is likely to tighten as diesel specifications improve. Refiners reluctant to invest may accept a reduction in diesel yields. These factors are important considerations at the 50 ppm level. A move to 10 ppm will make diesel supply more difficult but the degree to which it will further tighten the supply/demand balance may be limited. Changes to other diesel specifications, such as reduction of T95 distillation and density may well have a stronger impact on supply than the sulfur reduction to 10 ppm.

Timing of Introduction of Specifications

The study was carried out on the basis that ULS gasoline and diesel specifications would be introduced at the beginning of 2008. The impact of introduction at a later date is likely to be minor provided that the date of introduction is agreed relatively quickly and within the next year. Assuming the introduction date is agreed before the end of 2001, refiners will have six years to prepare for the introduction. However, there may be some implications for the introduction of the 50 ppm quality. If a decision on ULS gasoline and diesel is delayed much beyond the end of 2000, European refiners are likely to delay project investments for 50 ppm due to the uncertainty concerning subsequent reductions to 10 ppm. If refiners are aware that 10 ppm specification is due in 2008, they are likely to modify their investments made to meet the 50 ppm specification to ensure that they can be subsequently upgraded to meet the 10 ppm limit to avoid stranded investments.

If ULS gasoline and diesel is introduced later than 2008, some of the new technologies under development currently are likely to have made further progress and ultimately the costs incurred for investments are likely to be lower than for the introduction in 2008.

Intermediate Sulfur Content Specifications

The relationship between the sulfur content of gasoline and diesel and the investment requirement and associated costs between 50 ppm sulfur content and 10 ppm sulfur content are not linear. Moving to lower and lower sulfur contents means that the most difficult sulfur containing species must be treated. The cost of treating these species are generally higher than treating the easier species. There is no clear break point or step change in investment levels moving between the 50 ppm level and the 10 ppm level with one possible exception. As discussed earlier, the sulfur content of LPG streams and LPG derived gasoline and blending components such as alkylate and MTBE are not generally considered when producing gasoline at 50 ppm sulfur content. However, the sulfur content of these streams may often be in the 20-30 ppm range. As a result, a reduction in sulfur content of gasoline below 30 ppm require these streams to be further processed. However, the additional investments required to reduce the sulfur content of these streams to below the 10 ppm level are expected to be relatively minor.

Limited Introduction

Purvin & Gertz was asked to consider the limited introduction of ULS gasoline and diesel at a 25% share of the market level. The yardstick refinery for Northern Europe for both cat cracking and hydroskimming were used to assess the implications of the limited introduction.

For the hydroskimming case, the cost of production of 10 ppm gasoline is essentially zero. However, this does not mean that the cost to the industry as a whole for 25% introduction would be zero. As discussed in Section IV, many refiners are considering trading intermediate products between refineries to enable them to meet the 50 ppm gasoline sulfur content specification. In particular, it is likely that sulfur-free reformate produced from hydroskimming refinery configurations is likely to be exchanged with high sulfur content FCC gasoline streams. The 25% introduction of 10 ppm gasoline, if produced from hydroskimming refineries, would reduce the opportunities for exchange of components between the hydroskimming refineries and cat cracking refineries. As a result, although the hydroskimming refineries would not see any additional costs for producing a 10 ppm sulfur content material there may be additional costs arising due to the limitation of the opportunities to exchange product with other refineries. Since many hydroskimming refineries are expected to buy in FCC gasoline to help them meet the 35% aromatics specification, production of low sulfur content 10 ppm gasoline would restrict their ability to blend these high sulfur components. At the same time, the catalytic cracking refineries would be limited in their ability to import sulfur-free reformate streams for blending with their high sulfur content FCC gasoline streams. As a result, catalytic cracking refineries would incur additional costs.

Since Purvin & Gertz' yardstick catalytic cracking refinery is actually a combination of hydroskimming and catalytic cracking facilities the costs associated with production of 25% gasoline and diesel from this refinery configuration are more representative. The lower sulfur content streams produced from the hydroskimming part of the refinery can be utilized to produce the 10 ppm sulfur content material while the high sulfur content, more difficult streams can be retained for production of 50 ppm gasoline. The case with limited introduction of ULS gasoline reduces overall capital investment to some extent. In this case the low cost investments in light FCC gasoline and LPG sweetening processes could be undertaken. Only a slight increase in FCC gasoline hydrotreating severity would be required versus the Base Case. Capital costs for this case were estimated to be around €2 million compared to €5 million in the 100% ULS gasoline case.

Production of 25% ULS diesel would also require lower investments. In this case the diesel hydrotreater would still require some modification but the severity increase would not be so great. Capital costs would likely be closer to €10 million compared to €33 million in the 100% ULS diesel case.

Synergistic Effects

There is little synergy in the investments made to produce ULS gasoline and diesel. The production of ULS gasoline mainly involves the post treatment of streams derived from the FCC unit. These investments do not in any way assist the production of ULS diesel. Investments in FCC feed treatment or moderate conversion hydrocracking will assist with the production of both ULS gasoline and diesel. However, this approach cannot be justified on a sulfur reduction basis only and these relatively costly investments are likely to be limited.

TABLE VI - 1
ECONOMIC RESULTS
(2000 Euros)

	Northern Europe				Southern Europe			
	Gasoline		Diesel		Gasoline		Diesel	
	Low Cost	High Cost	Low Cost	High Cost	Low Cost	High Cost	Low Cost	High Cost
Capital Costs, M€	-5	-24	-33	-128	-5	-91	-27	-116
Operating Costs, M€/yr	-1.3	-2.5	-1.4	-4.7	-1.5	-1.8	-1.5	-4.6
Cost, €/tonne								
@4% Discount Rate	-0.6	-1.5	-1.9	-7.1	-0.8	-4.1	-1.8	-6.7
@7% Discount Rate	-0.5	-1.3	-1.8	-6.7	-0.7	-3.9	-1.6	-6.2
@12% Discount Rate	-0.4	-1.1	-1.6	-6.1	-0.5	-3.7	-1.4	-5.6
Cost $/tonne								
Auto Oil 1 Approach (1)	-0.2	-1.1	-1.9	-7.0	-0.3	-4.8	-1.6	-6.4
Price Premium (1), €/tonne								
CRF 8%	0.8	1.9	2.4	9.1	1.1	5.2	2.3	8.5
CRF 15%	0.9	2.7	3.8	14.5	1.3	8.8	3.4	13.5
CRF 20%	1.0	3.2	4.8	18.5	1.4	11.4	4.3	17.1

Notes : 1 € = 0.95 $

(1) Capital Cost + 9.75*Operating Cost / Production in 15 years

(2) Price premium for ULS fuel versus 50 ppm fuel

TABLE VI - 2
ECONOMIC RESULTS
(2000 US dollars)

	Northern Europe				**Southern Europe**			
	Gasoline		Diesel		Gasoline		Diesel	
	Low Cost	High Cost	Low Cost	High Cost	Low Cost	High Cost	Low Cost	High Cost
Capital Costs, $M	-5	-22	-31	-122	-5	-86	-26	-110
Operating Costs, $M/yr	-1.2	-2.4	-1.3	-4.4	-1.4	-1.7	-1.4	-4.4
Cost $/tonne								
@4% Discount Rate	-0.5	-1.4	-1.8	-6.8	-0.8	-3.9	-1.7	-6.3
@7% Discount Rate	-0.5	-1.3	-1.7	-6.3	-0.6	-3.7	-1.5	-5.9
@12% Discount Rate	-0.4	-1.1	-1.5	-5.8	-0.5	-3.5	-1.4	-5.4
Cost $/tonne								
Auto Oil 1 Approach (1)	-0.2	-1.1	-1.8	-6.7	-0.3	-4.6	-1.5	-6.1
Price Premium (2), $/tonne								
CRF 8%	0.7	1.9	2.3	8.6	1.0	4.9	2.2	8.1
CRF 15%	0.9	2.6	3.6	13.8	1.2	8.4	3.3	12.8
CRF 20%	1.0	3.1	4.6	17.5	1.3	10.9	4.1	16.2

Notes :

(1) Capital Cost + 9.75*Operating Cost / Production in 15 years

(2) Price premium for ULS fuel versus 50 ppm fuel

APPENDIX 1

REFINED PRODUCT DEMAND, QUALITY AND SUPPLY

REFINED PRODUCT DEMAND

Purvin & Gertz' outlook for refined product demand in the European Union fifteen countries (EU15) is based on the demand projections made in its multiclient study "European Refining to 2015" produced last year. The projections were developed on a country-by-country basis details of which can be found in the study. The projected demand for the EU 15 is shown in Table A-1-1. The key factors affecting demand for the major products are discussed below.

GASOLINE

Gasoline demand in the EU15 has been slowly declining since 1992. Estimated demand in 1999 was very close to the 1990 level. Our projection shows continued slow decline in demand through to the 2005 period before the rate of decline in demand accelerates later in the forecast period.

The accelerated demand decline of gasoline is mainly a result of the commitment by car manufacturers to meet reduced CO_2 emission levels of 140 grams CO_2/kilometer average in the new car fleet sold in 2008. This commitment is expected to result in car manufacturers offering higher efficiency gasoline engines, mainly using gasoline direct injection. More importantly, it is also expected that car manufacturers will encourage the use of more efficient diesel engine cars in place of gasoline powered cars to enable them to meet the average CO_2 emissions for the new car fleet. As a result, the acceleration of demand decline for gasoline is a result of increased efficiency of gasoline cars themselves and an acceleration of the growth in the percentage of diesel cars in the new cars sold.

KEROSENE

Kerosene demand is expected to continue to grow strongly in the EU15. The growth in kerosene demand is mainly for jet kerosene and increasing air traffic is expected to continue to increase jet kerosene demand. Our projection shows a somewhat lower rate of demand growth than seen through the nineties as limitations on expansion of airport capacity limits growth to some extent.

DIESEL

Diesel demand in the EU15 has grown at an average of 3% per year through the nineties. A combination of commercial diesel growth related to growth in the economy, and supported by increased intra member trade, and increasing use of diesel engine passenger vehicles has supported this growth. In the future, the relationship between commercial diesel growth and growth in the economy is expected to be reduced somewhat as the economy matures. The move towards diesel engine passenger vehicles is expected to continue, as mentioned above, although diesel engine vehicles are also expected to increase in efficiency. As a result, we expect diesel demand to grow at just under 2% per year through the next ten years and at a slightly lower rate of growth than seen through the nineties.

HEATING GASOIL

Heating gasoil demand has actually grown very slightly in the nineties, although demand in 1990 itself was extremely suppressed due to high prices and very mild weather conditions. Demand has fallen versus the 1991 level. Heating gasoil demand is expected to continue to fall as natural gas continues to substitute for heating gasoil in both residential/commercial and industrial sectors. The decline rate is expected to be relatively moderate at around 0.5% per year as much of substitution by natural gas has taken place in many of the markets.

HEAVY FUEL OIL

Heavy fuel oil demand has declined by an average of 1.7% per year in the nineties. Substitution by natural gas in the power generation sector and, to a lesser extent the industrial sector, has been the main reason for the decline. Much of the decline has taken place in the last two years as Italy, the largest consumer of heavy fuel oil in the EU15, has made substantial reductions in heavy fuel oil use in the power generation sector.

Since much of the substitution for heavy fuel oil has already taken place in Northern Europe at least, we expect that the decline rate will be somewhat lower in the next ten years than in the last ten years. In addition, our projection also includes bunker fuel oil demand which is expected to continue to grow with increased trade and consumption of oil products. By 2010, bunker demand is expected to represent nearly 45% of heavy fuel oil demand in the EU15 compared to only 25% in 1990.

REFINED PRODUCT QUALITY

GASOLINE

The country-by-country demand projection developed by Purvin & Gertz for the European Refining to 2015 study included projections of gasoline demand by grade. The amalgamation of these country-by-country projections for the EU15 countries provides the gasoline split by grade as shown in the table below.

GASOLINE DEMAND BY GRADE
(Percent)

	EU15		NW Europe		Med	
	2005	2010	2005	2010	2005	2010
Premium Unleaded (95 RON)	82	88	81	86	84	89
Regular Unleaed (91 RON)	6	5	10	8	0	0
Super Unleaded (98 RON)	10	7	8	6	14	10
Lead Replacement	1	0	1	0	2	1
	100	100	100	100	100	100

For the EU15 countries, premium unleaded (95RON) is expected to represent around 82% of gasoline demand in 2005 increasing to around 88% by 2010. Super unleaded (98RON) is expected to represent around 10% of gasoline demand in 2005 falling to around 7% in 2010 as volumes reduce particularly in France. Regular unleaded demand is mainly in Germany and we expect this to represent around 5% to 6% of EU15 demand.

The countries considered by Purvin & Gertz to influence Northwest European pricing are, Germany through its connection to Rotterdam via the Rhine, Belgium, Northern France, Ireland, Netherlands, U.K. and Denmark. For these countries, the demand split by grade is slightly different with the proportion of regular unleaded gasoline somewhat higher due to the influence of Germany. For the Mediterranean countries, Southern France, Greece, Italy, Portugal and Spain the gasoline split shows a somewhat higher proportion of higher octane super unleaded (98RON) and virtually no regular unleaded consumption.

REFINED PRODUCT SUPPLY

In its “European Refining to 2015” study, Purvin & Gertz modeled the European refining industry by dividing Europe into three regional trading blocks. The North region consisted of Northern France northwards to Scandinavia and westwards to Ireland. The central region consisted of Germany, Austria and Switzerland the northeast European countries. The south region consisted of the countries bordering the Mediterranean including southern France and also Bulgaria and Romania. Linear Program (LP models) for each of these refining regions were developed and first calibrated based on 1997 actual feedstock and yield data. Since modeling the refining industry using this approach leads to some over-optimization versus actual performance, calibration factors on utilization of unit capacity and other operating parameters were developed in the calibration case. These calibration factors were then carried forward to the future cases.

Future cases were then run for each region taking account of the changes in product demand and quality, feedstock slate and trade patterns. It should be noted that the product quality assumptions for gasoline and diesel for 2005 included some tightening of specifications besides sulfur content and gasoline aromatics. The assumptions are shown in Section III. Due to the interaction of trade between various regions this was an iterative process. Announced refining capacity changes were built into the future models and capacities on other units were left open such that capital investments could be made to meet the required production slate. The actual and forecast refinery balances for Europe as a whole are shown in Table II-2. It is not possible to break out the EU15 countries due to the regional trading block approach used. However, the general trends for Europe as a whole are in line with the trends in the EU15 countries.

The combined results of the refining balances for the three European regions are shown in Table A-1-2. The key factors are discussed below.

Crude Slate

The crude slate processed in Europe as a whole is not expected to change significantly. The crude runs for Europe are summarized below.

EUROPE CRUDE SLATE

	1997	2005	2015
Crude Run (MT/yr)	690.5	745.6	800.1
(MB/D)	15.3	16.5	17.6
Wt%			
Light Sweet	45.5	46.8	47.3
Light Sour	47.8	44.1	45.8
High/Med TAN N.Sea	3.9	6.2	4.0
Heavy Sour	2.9	2.9	2.9
	100.0	100.0	100.0
^{o}API gravity	33.2	33.1	33.2
Sulfur content (wt%)	1.0	1.0	1.0

In terms of API gravity and sulfur content the European crude slate is little changed through the forecast period. However, the percentages of the types of crude processed shows that some changes in the crude mix are expected. The proportion of light sweet crude processed increases slightly from an estimated 45.5% in 1997 to 47.3% by 2015. With increased production of high/medium TAN crude from the North Sea expected over the next few years we expect the proportion of these crudes processed in Europe to increase somewhat, particularly in the time period through 2005. As many of these crudes are offshore loaded they will need to be processed in Europe. The proportion is expected to increase from an estimated 3.9% in 1997 to 6.2% by 2005 before reducing somewhat, as North Sea production levels begin to decline, to around 4% by 2015. The increased processing of these crudes is mainly expected to back out light sour crude imported mainly from the Middle East. As a result, light sour crude processing is expected to fall from 47.8% in 1997 to 44.1% in 2005 before recovering, as North Sea production begins to decline, to around 45.8% by 2015.

Yields

Overall refinery yields for Europe are shown in Table A-1-2 and summarized in the table below.

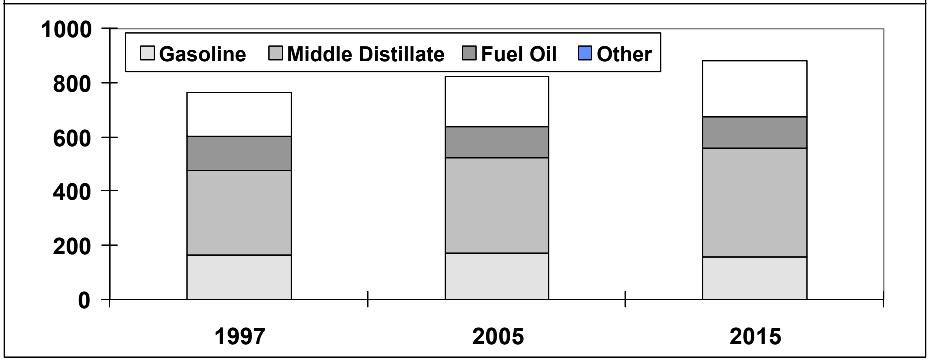
EUROPE REFINERY YIELDS
(Million tonnes unless noted)

	Actual	Projected		Yield wt% on input	
	1997	2005	2015	1997	2015
Crude Input	690	746	800	90.3	90.9
Other Feedstocks	75	80	81	9.7	9.1
	765	825	881	100.0	100.0
LPG	18	22	25	2.4	3.0
Naphtha	48	53	60	6.3	6.8
Gasoline	166	171	159	21.6	18.0
Middle Distillate	310	352	399	40.6	45.3
Heavy Fuel Oil	125	113	116	16.4	13.2
Other	49	57	62	6.4	7.0
Total Products	717	769	821	93.8	93.2
Fuel & Loss	48	56	60	6.2	6.8
Total Output	765	825	881	100.0	100.0

Total input into European refineries in 1997 was estimated to be 765 million tonnes of which 690 million tonnes was crude oil. Refinery intake is expected to increase to 881 million tonnes by 2015. This represents an annual growth rate of 0.9% per year through the period.

Net product output is expected to increase from an estimated 717 million tonnes in 1997 to 821 million tonnes by 2015. Production of LPG, naphtha, middle distillate and other products is expected to increase. Production of gasoline and heavy fuel oil is expected to reduce. The main increase is expected to be in middle distillate production which is expected to increase from 310 million tonnes in 1997 to 399 million tonnes in 2015. Fuel and loss is also expected to increase as refinery throughput and processing intensity increases.

FIGURE A-1-1
EUROPE REFINERY YIELDS
(Million Tonnes)



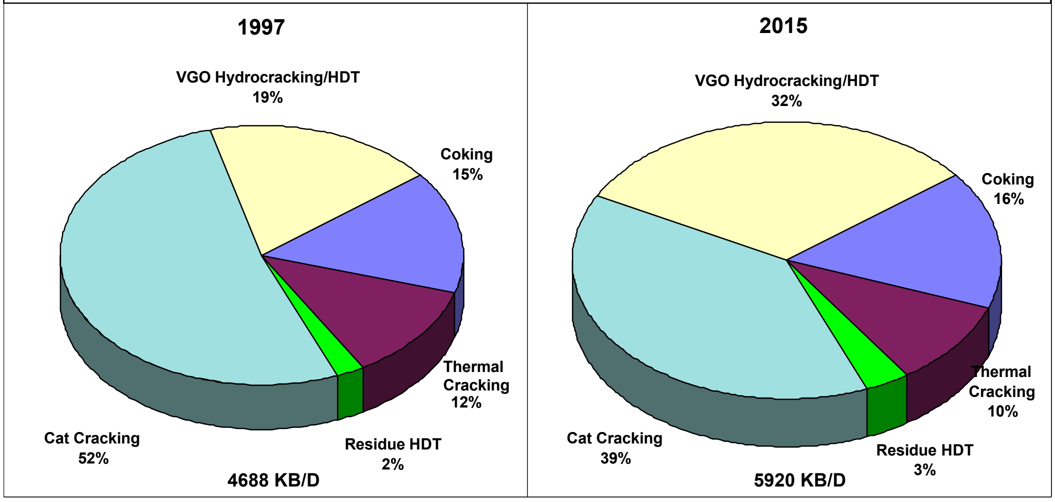
Refinery yields expressed as a percentage of input show the trends more clearly. The yield of middle distillate is expected to increase by nearly 5% to just over 45% of input. More moderate increases in yields are expected for LPG, naphtha and other products. These increases are at the expense of yields of gasoline and heavy fuel oil. Gasoline yield is expected to reduce by almost 4% with most of the reduction coming after 2005 as gasoline demand begins to fall more quickly. The heavy fuel oil yield is expected to fall by just over 3% but in this case most of the decline is expected to take place before 2005.

Capacity

European crude distillation capacity totaled 16.8 MB/D (830 MT/yr) at the beginning of 1998. Overall crude distillation capacity utilization in 1997 was estimated to be just under 84% for the region as a whole. However, there are considerable regional differences and most of the excess capacity is uneconomic and concentrated in a few countries. Crude distillation capacity is expected to increase to nearly 17.9 MB/D (879 MT/yr) by 2015. This represents an annual growth rate over the period of around 0.9% per year and is in line with the growth in demand for oil products in Europe. This rate of increase is slightly higher than would be accounted for by capacity creep which is typically around 0.5% per year. As a result, expansion of some crude distillation units will be required. We expect that these expansions will take place at the larger refineries and may be combined with investments to allow feedstock flexibility such as processing condensates or higher proportions of medium/high TAN crudes.

To meet the reducing heavy fuel oil demand requirement, fuel oil conversion capacity additions are expected to continue in the future. We have expressed fuel oil conversion capacity in terms of FCC equivalents. This expresses the degree of fuel oil conversion for an upgrading unit relative to that achieved by a cat cracker. For example, the FCC equivalent of a visbreaker is 0.25 and a delayed coker 1.7. In 1997, total FCC equivalent conversion capacity was just under 4.7 MB/D (244 MT/yr) and represented 28% of crude distillation capacity. A further 1.2 MB/D (64 MT/yr) of fuel oil conversion capacity is expected to be added before 2015. This increases the FCC equivalent as a percent of crude distillation capacity to 33.2%. The addition rate of just over 3.5 million tonnes is somewhat lower than the rate of addition seen in Western Europe in the last ten years. In addition, conversion capacity additions are expected to be orientated towards middle distillate production and less aimed at gasoline production as has been the case in the past through FCC investments.

FIGURE A-1-2
EUROPE RESIDUE CONVERSION CAPACITY
(FCC Equivalents)



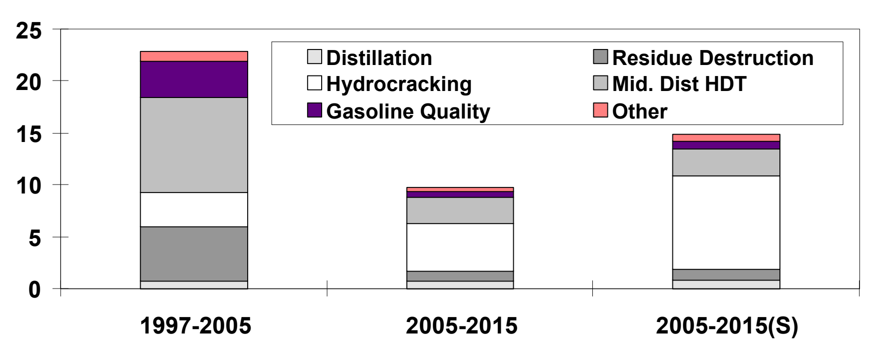
To meet the change in demand slate towards middle distillate and to achieve the higher quality middle distillate products required, further refinery upgrading is required. Investment in hydrocracking capacity, both full conversion standalone units and moderate conversion units upstream of FCC units, is expected to take place. In addition, to meet the 50 ppm sulfur content in diesel in 2005 existing middle distillate hydrotreating capacity will require replacement or modification. The higher quality diesel requirement and increasing proportion of diesel in the middle distillate pool, makes it increasingly difficult to blend light cycle oil (LCO) produced from FCC units. As a result, we expect to see additions of LCO hydrotreating capacity such that the light cycle oil can be upgraded to heating gasoil or even into the diesel blending pool.

Capacity changes to meet the gasoline specification changes are expected to be mainly aimed at lowering benzene, aromatics and sulfur content. We expect to see capacity additions of reformate splitting, isomerization with benzene saturation where required, alkylation and oxygenate production mainly aimed at benzene and aromatics control. In our refining projections we have assumed that most of the light and heart cut reformate produced as a result of these modifications is further upgraded to gasoline. In practice, refineries integrated with aromatics production units either at the same site or within the company's own system may well use these streams as aromatics plant feedstock. This will avoid the capital expenditure associated with benzene saturation necessary to allow the material to be used in gasoline. As a result, the capacity additions of isomerization and benzene saturation shown in Tables II-5 and II-6 are likely to be higher than actually seen in the industry. Gasoline sulfur content reduction is expected to be mainly taken care of by a combination of FCC feed treatment and FCC gasoline splitting and hydrotreatment. Production of oxygenates from refinery streams is expected to increase to allow dilution of undesirable properties of other gasoline components and to recover octane lost through benzene and aromatics content reductions.

Capital Investments

Total refinery capital expenditure in Europe is estimated to be $22.9 billion in the 1997 to 2005 period and a further $9.7 billion in the 2005 to 2015 time frame. In the 1997 to 2005 period 40% of the investments are related to middle distillate hydrotreating. Residue destruction investments represent 23% of the investments in the same period. Around 60% of the residue destruction investments are associated with Integrated Gasification Combined Cycle (IGCC) plant investments already announced. As shown below, around 14% of the total investments are in hydrocracking type processes and 15% of the investments are directly related to changes in gasoline quality.

FIGURE A-1-3
EUROPE REFINERY INVESTMENTS
($1998 Billion)



Beyond 2005, the majority of the investments are related to the increasing requirement for middle distillates both in terms of quantity and quality. Hydrocracking investments represent 47% of the expenditure in the 2005 to the 2015 period while middle distillate hydrotreating investments represent a further 26%. In addition, hydrogen plant associated with these units requires a further 4% of the total capital investment in the period. Further investment in residue destruction processes beyond 2005 represent around 10% of the total, much of which is associated with capacity creep in existing units.

In the sensitivity case, capital expenditure is somewhat higher at $14.8 billion beyond 2005. Hydrocracking investment dominates in this period due to the increased diesel quality requirement. In this case, hydrocracking represents 60% of the total investment expenditure. Capital investments on the other processes are similar to those in the base case for 2015. It was assumed that a mix of revamped and new hydrotreating capacity will be required to meet the lower polyaromatics specification. If revamps are not possible, additional capital expenditure of around $3.4 billion is expected to be required.

REGIONAL CRUDE SLATE

The section above describes the general trends projected for the refining industry in Europe as a whole. The general trends are similar irrespective of the European region. However, the magnitude of the changes does vary from one region to another and Purvin & Gertz analyzed North, Central and South regions in its "European Refining to 2015" multiclient study. Details of the regional analysis can be found in the study.

One of the more significant regional variations is crude slate. The table below shows the percentage of crude processed by type in the three regions.

CRUDE SLATE BY REGION

	North		Central		South	
	1997	2005	1997	2005	1997	2005
Crude Run (MT/yr)	287.3	308.2	149.2	162.7	253.9	274.8
Wt%						
Light Sweet	59.2	57.9	45.6	45.5	30.0	35.0
Light Sour	31.5	28.0	50.3	49.5	64.6	59.0
High/Med TAN	7.3	12.1	3.3	4.0	0.4	1.0
Heavy Sour	2.0	2.0	0.9	1.0	5.0	5.0
	100.0	100.0	100.0	100.0	100.0	100.0
^{O}API gravity	33.7	33.4	32.3	32.5	33.7	33.5
Sulfur content (wt%)	0.9	0.9	0.9	0.9	1.3	1.2

As shown above, the crude slate processed in Northern Europe contains a higher proportion of lower sulfur content crudes (light sweet and High/Med TAN) than the other regions. The combined light sweet and High/Med TAN crudes represent around 67% and 70% of the crude slate in 1997 and 2005 respectively. The Northern Europe region most closely corresponds to the Northwest Europe regions used for Purvin & Gertz' yardstick refinery discussed later. The Southern Europe region is the closest corresponding region to the Mediterranean refinery yardstick.

TABLE A - 1 - 1
EUROPEAN UNION 15
REFINED PRODUCT DEMAND FORECAST

(Million Tonnes)

					Gasoil/	Of Which:			Of Which:	Lubri-			
	LPG	Naphtha	Gasoline	Kerosene	Diesel	Gasoil	Diesel	HFO	Bunkers	cants	Bitumen	Other	TOTAL
1985	18.8	31.2	101.7	23.4	188.4	100.0	88.4	114.5	21.0	5.3	12.9	12.7	508.8
1990	19.4	32.5	118.2	30.4	198.2	83.6	114.5	106.3	27.0	5.5	15.9	15.2	541.5
1991	21.0	31.9	119.7	30.5	210.4	92.6	117.8	108.6	26.9	4.8	16.7	16.7	560.3
1992	20.5	32.3	122.6	32.2	212.9	90.2	122.7	107.8	26.6	4.9	18.0	16.6	567.7
1993	20.3	30.0	121.8	33.5	215.2	90.4	124.8	103.1	28.5	4.7	17.2	15.3	561.2
1994	21.3	31.2	120.0	35.2	213.4	85.0	128.4	100.9	27.1	4.9	18.2	18.3	563.4
1995	20.8	35.8	119.1	36.6	218.8	86.0	132.8	102.5	27.1	5.1	17.8	16.5	573.0
1996	21.3	35.8	118.7	38.9	230.0	92.5	137.5	101.0	29.0	5.1	17.0	15.8	583.5
1997	21.1	36.7	118.1	40.5	229.7	88.3	141.4	97.3	31.7	5.2	17.4	16.5	582.6
1998	21.3	38.6	117.8	41.8	231.5	86.9	144.7	97.3	32.3	5.3	17.5	16.8	588.0
1999	21.8	39.4	118.0	43.3	235.2	86.4	148.8	91.7	32.7	5.3	17.7	17.1	589.5
2000	22.2	40.5	117.8	44.8	239.6	86.0	153.6	89.2	33.3	5.3	17.9	17.3	594.5
2001	22.5	42.1	117.3	46.3	243.8	85.6	158.2	88.5	33.8	5.4	17.8	17.5	601.0
2002	22.7	43.1	116.6	47.8	247.4	85.2	162.3	87.8	34.3	5.4	17.9	17.6	606.5
2003	23.1	44.6	116.2	49.3	250.7	84.8	165.9	87.2	34.7	5.4	18.1	17.8	612.5
2004	23.4	45.5	115.4	51.0	253.3	84.4	168.9	86.5	35.2	5.5	18.1	18.0	616.9
2005	23.6	46.2	114.5	52.5	255.5	83.9	171.7	86.0	35.7	5.5	18.5	18.2	620.6
2010	24.5	50.0	107.1	60.9	265.0	82.1	182.9	84.8	38.1	5.6	19.1	19.1	636.2
2015	25.3	53.8	99.8	70.0	272.0	80.0	192.1	85.6	40.7	5.8	19.8	19.9	651.9

TABLE A - 1 - 2
TOTAL EUROPE
REFINERY BALANCES

(Million Tonnes)

	Actual	**Forecast**	
	1997	**2005**	**2015**
Crude Input			
Light Sweet	314.3	348.6	378.5
Light Sour	329.7	328.9	366.4
High TAN	26.6	46.6	31.8
Heavy Sour	19.8	21.5	23.3
TOTAL	690.5	745.6	800.1
API gravity	*33.2*	*33.1*	*33.2*
Sulfur Content (wt%)	*1.0*	*1.0*	*1.0*
MB per day	*15.3*	*16.5*	*17.6*
Other Feedstocks	74.6	79.7	80.6
TOTAL INPUT	**765.1**	**825.4**	**880.6**
Production			
Propane	8.0	8.9	9.3
Butane	10.4	13.0	15.8
TOTAL LPG	18.4	21.9	25.1
Super Unleaded	11.9	16.0	10.1
Premium Leaded	57.2	7.9	1.9
Premium Unleaded	79.0	135.1	137.9
Regular Unleaded	17.5	12.4	9.0
TOTAL GASOLINE	165.6	171.4	158.8
Kerosene	48.2	58.7	80.7
Diesel	127.9	167.3	192.4
Heating Gasoil	103.8	102.5	99.0
Bunkers/Other Diesel	30.4	23.8	26.7
TOTAL MIDDLE DISTILLATE	310.3	352.4	398.9
Heavy Fuel Oil 0.5%S max	6.4	5.8	9.3
Heavy Fuel Oil 1%S max	26.0	32.0	41.1
Bunkers	36.3	42.0	46.5
Heavy Fuel Oil 3.5%S max	56.5	33.5	19.2
TOTAL HEAVY FUEL OIL	125.3	113.4	116.1
Naphtha	48.4	53.1	59.7
Other Products	49.3	57.1	62.0
TOTAL PRODUCTS	717.4	769.1	820.6
Refinery Fuel & Loss	47.7	56.2	60.0
TOTAL OUTPUT	**765.1**	**825.4**	**880.6**

APPENDIX 2

TABLE A - 2 - 1
PRICES ASSUMPTIONS 2008
(2000 Dollars)

Crudes, $/bbl		
Brent fob Sullom Voe	19.04	
Arabian Lt for NWE, fob	17.07	
Arabian Lt fob Sidi Kerir	18.21	

Products, $/tonne	**cif NWE cargoes**	**cif Med cargoes**
LPG	193	192
Naphtha	184	181
Regular Unleaded	196	
Euro Unleaded	204	213
Super Unleaded	227	235
Kerosene	203	197
Diesel EN590 50ppm	196	196
Gasoil 0.1%S	179	177
HFO, 1%S	103	104
HFO, 3.5%S	83	84

APPENDIX 3

TABLE A - 3 - 1
GLOSSARY OF TERMS

B/D and BPSD	Barrels Per Day and Barrels Per Stream Day
Catalytic cracking refinery	A refinery containing an FCC unit
CCR	Continuous Catalytic Reformer - a unit used to upgrade naphtha to gasoline with continuous regeneration of catalyst
CRF	Capital Recovery Factor
Cut Point	Initial and final boiling points of a distillation cut
End Point	Final boiling point of a distillation cut
FCC	Fluid Catalytic Cracker - used to convert residue to lighter products, mainly gasoline
Grassroots unit	A totally new process unit
Hydrocracker	A unit used to convert residue to lighter products, mainly naphtha and diesel
Hydrocracking refinery	A refinery containing a hydrocracking unit
Hydroskimming refinery	A relatively simple refinery with no residue conversion units
Isomerization Unit	Unit for upgrading light naphtha to gasoline
LCO	Light Cycle Oil - Low quality middle distillate produced from FCC
LPG	Liquified Petroleum Gas - including propane, butane, propene, butene
Middle Distillate	Refinery streams used for production of kerosene, diesel and heating gasoil
MTBE	Methyl Tertiary Butyl Ether - Octane enhancing blending component in gasoline
NPV	Net Present Value
Octane	Property of gasoline measured as Road Octane Number (RON) or Motor Octane Number (MON)
Semi Regen Reformer	Unit used to upgrade naphtha to gasoline which needs regular shutdowns to regenerate the catalyst
Straight Run	A material produced directly from distillation of crude oil
Sweet/Sour	Low sulfur content/high sulfur content
ULS	Ultra Low Sulfur - less than 30 ppm
VGO	Vacuum Gasoil - material produced from vacuum distillation mainly used for FCC or hrdrocracker feed
Viscosity cutter	Fuel oil blending component used to reduce viscosity