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The OURSE model: Simulating the World Refining Sector to 2030

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Executive summary[1]

The development of a model of the World Refining for the POLES model (Contract n°151559-2009 A08 FR – with the Joint Research Centre Institute for Prospective Technological Studies of Commission of the European Union) aims to represent the oil product's supply at a world-wide level in a global energy model.

The World oil refining industry faces to several challenges such as the increasing oil derivatives demand in the transport sector, the improvement of the specifications of these products, the crude oil availability and the limitation of carbon emissions. An aggregated refining model linked to the POLES energy model has been developed to study these questions.

The OURSE (Oil is Used in Refineries to Supply Energy) model is a world-wide aggregated refining model which is designed to simulate the world oil product supply for the POLES (Prospective Outlook for the Long-term Energy System) model. OURSE is able to simulate the impact on the world refining industry of changes in the crude oil supply (in costs and qualities) as well as in the oil product demand (in terms of level, structure and specifications).

OURSE also enables to assess the consequences of a carbon emission regulation (caps and taxes) as the adoption of various kinds of alternative fuel policies. More precisely, these impacts are evaluated as regards the world refining structure (investments), but also its balance (production and trade of petroleum products), its pollutant emissions (CO_2 and SO_2) and its costs (of production, investments, etc.).

The OURSE model is based on a linear programming (LP) model, that is frequently used in the refining industry, both for refinery management and investment analysis, since a marginal cost pricing is relevant for the oil products. Designed to represent the world-wide refining industry into the POLES model, the OURSE model has to contain a restricted number of equations. This justifies that OURSE includes a representative upgrading refinery defined for nine aggregated refining regions in the world that are North and central America, Latin America, North and South Europe, CIS, Africa, Middle East, China, Other Asia and Oceania.

Similarly, since directly linked to the number of crude oils considered, the model size is also reduced by considering, for each world refining area, an aggregated crude oil supply based on five representative crude oil qualities in the model. Lastly, a multi-plant approach is considered to make the OURSE model able to represent the oil product exchanges between the main regions in the world.

Simulations for 2030 were performed. Thus, the paper presents the results of a prospective exercise for the oil refining industry which has been carried out with the worldwide refining model OURSE according to the oil product demand projections of European Commission for Europe with the PRIMES model (European Commission, 2010) and the IFP projections for the rest of the World.

According to the European Commission's projections, the European oil product demand will slowdown by 14% between 2005 to 2030, reaching 566 Mtoe in 2030 (reference scenario). During the same period, the worldwide oil product demand will have increased by 23% up to 4411 Mtoe in 2030. The share of light, medium and heavy oil products will change with a decreasing share of heavy products and a more important consumption of medium distillates. Nevertheless, in the PRIMES

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European projections, the respective share of gasoline and diesel oil in the automotive fuel consumption are not strongly affected during the next two decades. However, the specification of the products will be more severe, especially for the marine bunkers (future IMO specifications as mentioned in the first part of the report which is dedicated to oil products).

On the supply side, the crude oil supply has been estimated until 2030. This analysis is based on IFP geosciences expertises. In 2030, the API degree of the conventional crude oil will slowly decrease. However, this will be balanced by the increasing share of condensates in the refinery supply and the availability of upgraded crude oil from the extra-heavy oil. Finally, the API degree of the refineries supply should remain quite unchanged.

In this context, the main results of the simulation are the following :

- The refineries production decreases in North America and in Europe whilst it strongly increases in the other regions of the World. The EU-27 production reduces to around 559 Mtoe in 2030, i.e. 555 Mt. The production of the recent years was 666.2 Mt in 2005 and 652.4 Mt in 2008. Thus, the European production should be 16% lower than the 2005 production which is the same evolution as the oil product demand.

- The trade flows of oil products point out the needs of gasoline of North America and the needs of diesel oil of Europe. The simulation of the oil product balance for EU-27 point out that the global production and consumption are equilibrated. However, there are some important flows of diesel oil imports (around 21% of the demand) and the European refineries should export around 18% of its gasoline production.

- The main investments concern the Middle East and Asia in order to reach the increasing demand. In Europe and North America, the slowdown of the demand affects the rate of use of the refining units. However, in Europe, some investments in essentially gasoil hydrodesulphurization units and at a lower level VGO/residue hydrodesulphurization (for bunkers quality) and hydrocracking units (as the diesel oil share in the total automotive fuel consumption continue to increase slightly) are required.

- The need for hydrogen in refineries contributes to an increase of CO_2 emissions. The direct emission due to the hydrogen production could stand for around 20% of the refineries emissions in 2030 (14% in 2005) as natural gas steam reforming should be the dominant technology. In addition the up-grading of extra heavy crude (Canada and Venezuela) will account for more than 13% of the refineries' emissions in 2030 (4% in 2005).

- The analysis of the marginal costs point out that the ratio gasoline marginal cost/crude oil price remains around 1.25 and the ratio diesel oil marginal cost/crude oil price is between 1.1 and 1.15 in most of the regions of the World.

Introduction

The objective of the OURSE model is to represent the refining activity at a world scale level. It will be included in the POLES (*Prospective Outlook for the Long-term Energy System*) model. Linear programming (LP) models are frequently used in the refining industry, both for refinery management and for investment analysis. As marginal cost pricing is relevant for the oil products, an LP model should be built for the refining model of POLES. The acronym of the refining model is OURSE - *Oil is Used in Refineries to Supply Energy*.

Because the model designed to represent the world-wide refining industry must have a limited number of equations, a representative refinery has been defined for a restricted number of regions in the world (corresponding to the POLES nomenclature). Moreover the crude oil supply has been aggregated (the size of the model is directly linked to the number of crude oil types which are introduced in the model). Finally, as the model has to represent the oil product exchanges between the main regions in the world, a multi-refinery approach is considered.

The OURSE was used for several studies concerning the global trends of the refining industry (Saint Antonin & Marion, 2011), the CO_2 emissions (Tehrani & Saint-Antonin, 2008) or some regional applications (Benyoucef and Lantz, 2011).

In this updated version of the OURSE refining model (Lantz and al., 2005), more processing units have been introduced in the refining scheme, a larger set of crude oil qualities is considered, all the figures concerning the CO_2 emissions from the refining processes and from the refineries fuel have been revised. An analysis of the international trade was realized to validate the representation of the flows of product between the regional areas. Finally, some new qualities of marine bunker fuels have been introduced in order to assess the consequences of the tightening specifications of these fuels in the future.

A first set of simulations for 2030 have been carried out with this new version of the OURSE model. A sensitivity analysis has been performed to assess the consequences of some more severe specifications on international marine bunkers. They are summarized in the third part of the report.

1. Description of the model

The oil refinery modelling in an energy model such as the POLES model involves the determination of the refining throughput, the investment pattern and the marginal costs through a model which represents this processing activity. As explained before, a linear programming (LP) model should be built to represent the refining industry.

The model represents the refining industry (transformation of crude oil and other feedstock in oil derivatives) and the petrochemical industry (aromatic and olefin production).

The main inputs of the model are (i) the oil product demand (in terms of both quantities and specifications), (ii) the crude oil availability, (iii) the CO_2 emissions restrictions and taxes. The main output are (i) the refineries throughput (activity level), (ii) the products blending, (iii) the products trade, (iv) the investments (technology dynamic of the refining processes), (v) the marginal costs of oil products (supply prices), and (vi) the pollutant emissions.

All the relevant techno-economic characteristics of the oil refining industry (such as technical processes, investment and operating costs, pollutant emission factors) are included in the model. As the model is designed to operate over the period 1997-2030, the most representative actual and future technologies have been be selected (Saint-Antonin & Marion, 2011). Moreover, the model allows the blending of biomass based derivatives (alcohol and ester) as well as GTL (gas to liquid) products.

The refining model of POLES is able to simulate the consequences of:

- changes of oil product demand such as a modification of the share of the automotive fuels (gasoline and diesel)
- changes of specification of oil products (sulphur content of oil products for instance)
- carbon emissions regulation (emission limits and taxes)
- adoption of alternative type of policies.

The OURSE LP model has the following set of equations :

- Balances of intermediate and final products
- Demand equations
- Product quality control equations
- Capacities constraints
- Crude oil supply
- Pollutant emission

A detailed description of the LP model is beyond the scope of this chapter and requires a lot of mathematical definitions and formulas. The refinery flows are indexed according to an appropriate combination of sub-sets of elements which characterize the crude oils and their types of cuts, the identification of the feeds, the units and their severities, the intermediate and the final products. Such detailed presentation of the refining modelling approach with linear programming should be found in Saint Antonin (1998).

1.1 Balances of intermediate and final products

The equations for the intermediate and final products balance the input quantities with the output quantities for each product. In order to obtain linear constraints and as the yields of the processing units are depending on operating conditions, some processes are operated considering different "severities" which represent several runs of the processing unit.

The material balance of an intermediate product expresses that the production is equal to the internal use. The production is represented by the multiplication of a yield and a quantity of feed. The yields of a processing unit are different for each severity and also depend on the type of input feed and the processed crude oil (and its distillation cuts). Total internal use is the sum of the possible transfers to finished products, as feed stock to other units, and to refinery fuel.

As an example, the flow diagram below (figure 1) displays, for a processing unit, the input feed CH0, the yields ($\alpha 1$, $\alpha 2$) in intermediate products (P1, P2) and the possible use of them (denoted Y1, Y2, Y3 in quantity term). Thus, the balance equation of the intermediate product P1 is written as :

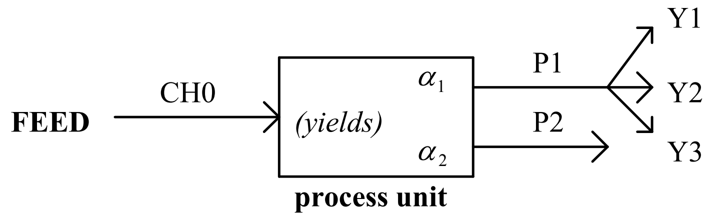
$$\alpha_1 CH_0 - \sum_k Y_k = 0$$

with the parameter,

α1: yield of P1

and the variables,
CH0: quantity of processed feed,
Yk: product quantity associated to the k-th possible transfer of P1.

Figure 1: flows of a processing unit



This example is very simplified. Let us consider for example an intermediate product whose quality depends on the type of feed, the severity of the unit, the crude oil and the crude distillation unit cut used. The number of equations relating to this product will be the multiple of the number of severity options considered by the number of feed stocks, the number of crude oils and the number of the types of cuts.

For a final product balance, the sum of the quantities of the blend components used for the product is equal to the delivered quantity of the finished product.

In these two balances, the variables are defined in terms of weight. In some cases, the balances have to be also defined in terms of volume because certain specifications (such as road vapor pressure for gasoline) are expressed in volume. Therefore, the equations have to be modified by introducing the product's density.

A particular balance is the refinery fuel balance. In this equation, the refinery fuel demand is satisfied by either intermediate or final products. These products have different calorific values. Thus, on the supply side, the refinery fuels (defined in weight term) are weighted according to their calorific value. On the demand side, we consider that the refinery fuel requirement is proportional to the inputs to the processing units.

1.2 Demand equations

The supply (production and imports) must equate to demand (domestic consumption and exports). In a multi-refinery model such as the OURSE model, several refining areas have been distinguished. However, each refining area is also an energy demand area and represents a group of countries: this aggregated approach is justified in the fourth section. Local domestic consumption (for an area which stands for several countries) could be supplied either by the local refining industry or by a refinery from another area with a transportation cost. The exchanges of intermediate products between the refineries are not allowed in this model as they only represent limited flows in this context.

Consequently, two types of equations have been introduced in the model. The first is related to the refinery supply, the second to the energy demand. Foreign exchanges are introduced in the equations of countries demand as exchanges with the rest of the refining areas.

1.3 Product quality control

The final products must meet a number of legal and technical quality specifications such as the octane number (for gasoline) or the sulphur content (for gas oil and residual fuel oil). Some specification constraints can be written as linear equations. Thus, a linear constraint is obtained by multiplying the intermediate product quantities (in volume or in weight term) by their qualities and by setting a minimum or maximum specification to the final product. When there is no linear relationship, this characteristic is replaced by an index which can be used in a linear constraint.

1.4 Capacity constraints

The input flows of a processing unit are limited by its capacity. Because the oil refinery model is a long-run model it allows capacity expansion. Thus, for each refining unit the capacity constraint can be expressed as: the sum of the input flows (weighted by their delivery coefficients) minus the capacity expansion is lower than or equal to the existing capacity.

In the case of a single refinery, the investment cost is generally a non-linear function of the unit size and the capacity expansion has to be treated through several variables associated with different investment costs. However, in an aggregate model, we can assume that capacity expansions are the result of the addition of processing units with given "economic" size, and thus that costs are proportional to capacity increases.

1.5 Crude oil supply

The crude oil is first processed in the atmospheric distillation unit. This unit splits crude oil into several cuts: gases, straight-run gasoline, kerosene, straight-run gas oil, residue, etc. Depending upon requirements there is for a given crude oil, some flexibility regarding the quantity of each cut which can be obtained. This flexibility is obtained by a modification of the cut point (temperature at which a product is cut). Therefore each crude oil can be "cut" in different ways. Various sets of cuts are introduced in the model (therefore various set of yields at the atmospheric distillation). The total quantity of crudes to be processed must be equal to the sum of the different quantities processed through different sets of cuts.

As the number of equations of the LP model is approximately proportional to the number of crude oils, a limited number of typical crude oil have been defined. Then, the different qualities of crude oil are represented as a combination of the typical crude oil.

Finally, for each "crude oil supply" region of the world, the sum of the output flows of crude is bounded by a maximum production level. Furthermore, the sum of the input flows is equal to the crude oil supply of each processing region (each refinery).

1.6 Pollutant emission

The pollution that we are dealing with is the atmospheric pollution due to SO_2 and CO_2 emissions from the refinery. The pollutant emission comes from the refinery stack emissions, i.e. mainly from the burning fuel. Two equations are also needed to introduce pollutant emission restrictions in the model: the total quantity of pollutant in the refinery fuel and the total quantity of stack emissions. In the first equation, we assume that the pollutant contents of the refinery fuels are proportional to their quantities. The stack emissions are also proportional to the quantities of the refinery fuels burnt. Furthermore, we also consider the direct emissions from the processing units (CO_2 emissions from hydrogen production plants)

Then, the pollutant emission in the stack emissions can be restricted with an other constraint. Pollution permits can be introduced in the objective function.

1.7 Objective function

The objective function to minimize is the refining cost, the supply cost (imported crude oil price), the delivery costs of the oil products to the consumption areas and (eventually) pollution permits. The refining cost includes, for each refinery, the processing cost and the investment cost.

The investment decision behaviour is a myopic forward process. For each period, investment decision only depends on the current demand and is implemented during the same period. The cost coefficients of the capacity expansion are the annual equivalent investment costs.

2. General framework and data of the OURSE model

The OURSE model is based on the LP refining model described above. As it has already been mentioned, the refining model is dedicated to the determination of petroleum product prices, of oil and oil products flows and of investment needs in this industry.

Several aggregated refining areas supply the petroleum products in the World. One representative refinery with a reduced crude oil supply represents the refining structure of each area. This typical refinery is called a "deep conversion refinery" to process a large set of crude oil and to provide light products (Favennec, 2001).

In the next paragraphs, we describe the representative deep conversion refinery, the crude oil supply aggregation, the oil product demand breakdown and the refining areas which have been settled for the OURSE model.

2.1 A representative deep conversion refinery

Important changes in the trend in growth and in the composition of demand for oil products after the first oil shock had a significant impact on the structure of the refining industry. The share of heavy products went down from 33% to 14% between 1973 and 2008, whist the medium distillate and light products shares grew from, respectively, 34% to 47% and 34% to 39% over the same period. Furthermore, the specification of the oil products became more and more severe: for instance, the sulphur content of diesel oil in the European Union decreased from 350 ppm at the beginning of 2000s to 10 ppm in 2009. More detailed analyses could be found in Favennec (2001), Carollo (2011) or Silva (2010).

Originally, Simple refineries (also named hydroskimming refineries) have atmospheric distillation (topping unit), a catalytic reformer (to produce high octane number compounds for gasoline blending) and middle distillate hydrodesulphurisation unit. Thus, the basic hydroskimming refinery could thus no longer meet requirements by processing a medium crude oil and it was therefore necessary to add processing units to obtain a much lighter product mix from the same type of crude oil.

Nowadays a typical refinery required to supply a large proportion of light products (gasoline) or middle products (diesel oil) must have a series of upgrading units downstream from the atmospheric distillation unit, enabling it to convert the heavy cuts into light or middle distillate cuts.

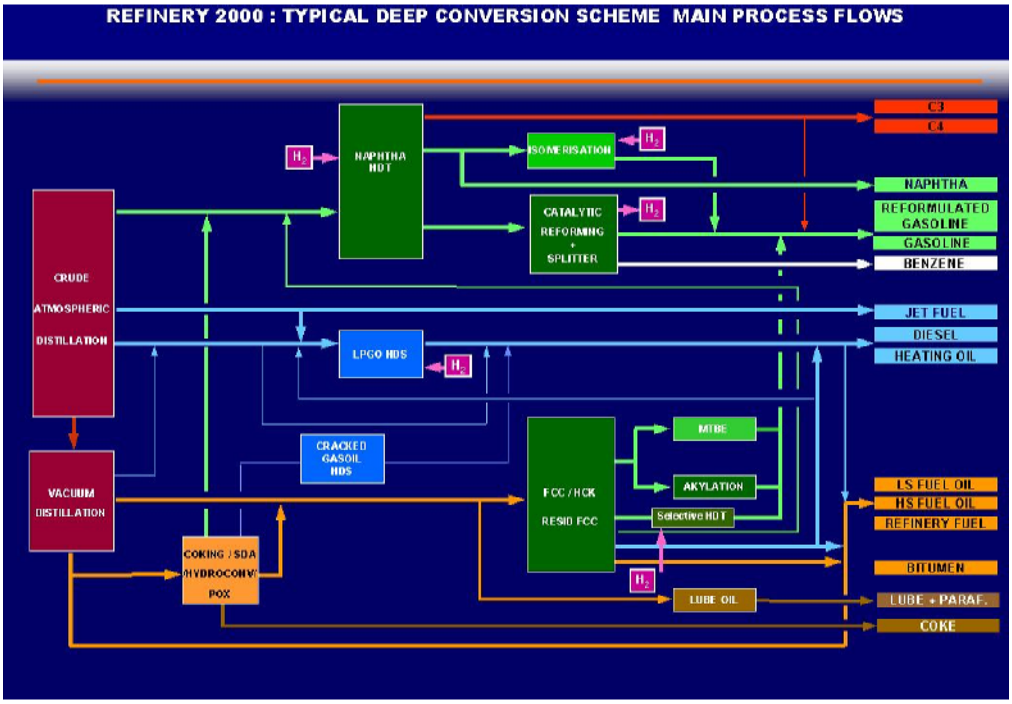
The retained refining structure initially consisted in the most common processing units, among which an atmospheric distillation unit, a vacuum distillation unit, a catalytic reforming unit, a gas oil hydrodesulfurization unit, a MTBE unit as well as an ETBE, a catalytic cracker and four types of hydrocracker, combined with alkylation and isomerisation units to improve the quality of the gasoline pool, and visbreaking and coking units to process residues from these units. The coking process is indeed a deep conversion unit; nevertheless this technique is used in several refineries.

This conversion refinery is relevant to the current structure of both demand and supply, but it may need to be adapted in line with future developments or in some scenarios considered over the next thirty years. To face the possible evolutions of demand and measures that could be adopted about the tightening of petroleum product specifications such as reduction in the sulphur content in diesel oil and heavy fuel oil, additional deep conversion units have been added in the modellised refining structure. The chosen deep conversion scheme is made up of a C5 desasphalting unit, a DAO hydrotreating unit, a partial oxydation unit and a deep hydrodesulfurization unit.

Since the previous version of the OURSE model, an H-Oil unit (for upgrading atmospheric and vacuum residues) and a hydrodesulphurization unit of vacuum gas oil have been introduced in the model. The refining scheme is presented in figure 2 and the complete list of the processing units as well as the world-wide refining capacities are given in Annex 1. A detailed description of the refining schemes could be found in Wauquier (1995).

We assume the technical data are the same for all the refining areas as we assume that there is no technological barrier for this industry.

Figure 2 - A representative deep-conversion refinery



Refining costs can be considered in three different categories: operating variable costs, fixed running costs and capital charges. The operating variable costs in the LP model include the catalysts, solvents and chemicals. The investment for a unit is calculated from the total cost of the equipment located within the "battery limits", this terminology being explained below..

The battery limits investments (B.L.I.) includes the civil works, the piping located within the unit area, electrical installations, instrumentation, etc. Anything outside the refining units, such as product lines, administrative installations, storage facilities and units to produce utilities (steam, electricity, water, ...), that is not included in B.L.I., constitute off-sites of a refinery: their costs are estimated as a part of B.L.I., suited to each refining unit.

The calculation of equivalent investment costs and fixed running costs are both based on the sum of the B.L.I. and off-sites. Fixed running costs -maintenance, labour, taxes, insurances and administrative expenditures- are considered as a share of the sum of B.L.I. and off-sites. Also, the equivalent investment cost which is introduced in the LP model is based on the depreciable capital cost *cc(j)* defined for a unit *j* as

$$cc(j) = (bli(j) + offs(j)) * (1 + ec) * (1 + rc) * (1 + fc)$$

where *bli(j)* and *offs(j)* are the B.L.I. and the off-sites costs of the unit *j*, *ec* is the engineering cost rate, *rc* is the process royalty rate and *fc* is the rate of the other financial costs. The rate of royalty concerns the supply of catalysts by engineering companies..

2.2 Crude oil supply

Several dozen different crude oils are processed in the World regions even if the concentration curves show that a large part of the supply is made up of only a few of them. Because the size of a LP model is approximately proportional to the number of crude oils considered, it is impossible to represent all of them in the refining model.

Both main characteristics of the crude oil are the API degree and the sulphur content. Among these, the degree API which is a measure of the density of the crude oil ($API = \frac{141.5}{density} - 131.5$). The API degree varies from an oil to the other one: the lower the API, the heavier the oil . Non-conventional crude oils have a API degree lower than 10.

The importance of the sulphur content comes from specifications of the oil products (the sulphur content was gradually reduced to reach the environmental requirements). Some specific processes should be required to reduce the sulphur content of the intermediate products in the refining scheme.

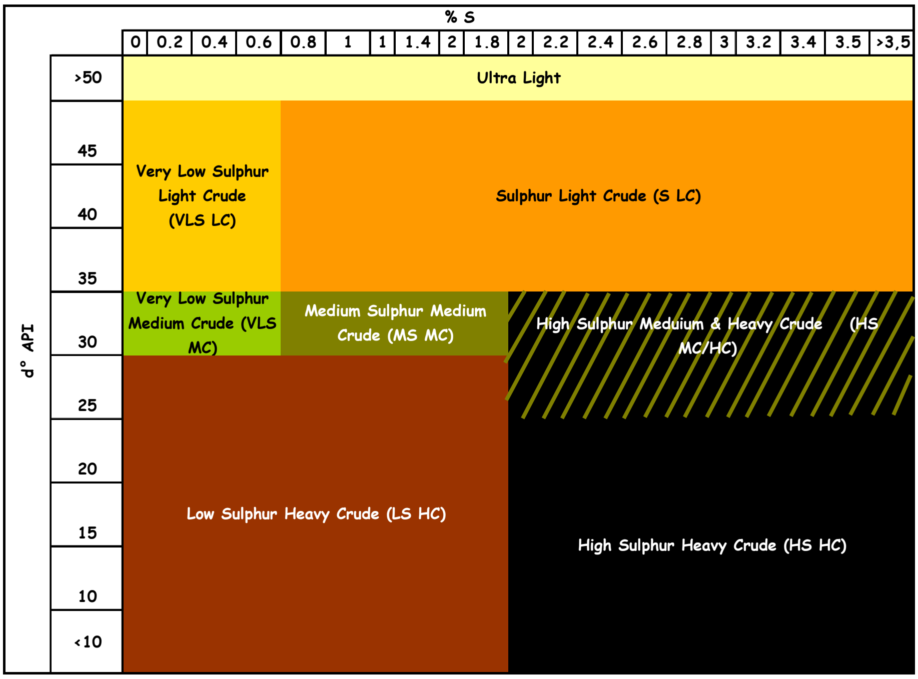
Consequently the crude oil supply has been "reduced" through a limited number of nine representative crude oils:

- Ultra Light Sweet Crude oil (Ultra Light),
- Sweet Light Crude Oil (Sw LC),
- Sour Light Crude oil (S LC),
- Sweet Medium Crude Oil (Sw MC),
- Medium Sour Medium crude Oil (MS MC),
- Sour Medium Crude Oil (S MC),
- Sweet Heavy Crude Oil (Sw HC),
- Sour Heavy Crude Oil (S HC)

– Bitumen and Extra-Heavy Oil (B XHC).

The decomposition of the various categories of crude oil following the API degree and the sulphur contents is given in the table 2.2.1

Table 2.2.1 - Main crude oil categories



The crude oil World-wide refining supply is presented the following figure 3 and table 2.2.2 :

Figure 3 – Crude oil supply in 2000 and 2005

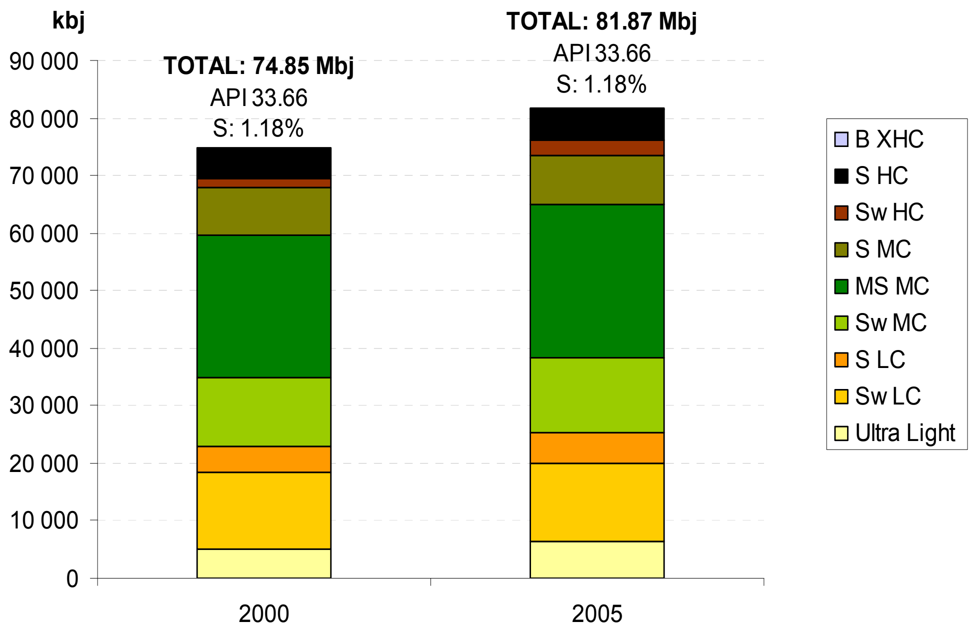


Table 2.2.2 – Crude oil supply in 2005

Crude oil	2005 (Kbj)	°API Mean	%S Mean	share vol 2005
Ultra Light	6 480	54.99	0.49	8%
Sw LC	13 416	39.41	0.20	16%
S LC	5 269	40.18	1.14	6%
Sw MC	13 099	31.23	0.19	16%
MS MC	26 651	32.07	1.42	33%
S MC	8 448	30.66	2.48	10%
Sw HC	2 664	19.57	0.52	3%
S HC	5 373	20.95	3.31	7%
B XHC	468	8.50	4.50	1%
Total	**81 868**	**33.66**	**1.18**	**100%**

Source : USGS, IEA

Finally, the 9 categories of crude oil production are summarized through a translation matrix in 5 main categories of crude oil which are considered in the refining model (table 2.2.3). Each crude oil production is a combination of the typical processed crude oil such as the combinations of API degree, sulphur content and yields at the topping unit approximate the characteristics of the original crude oil.

Table 2.2.3 Typical crude oil used in the refining model

Code	Crude oil name	°API	Sulphur (%m)	Conversion factor (b/t)	Yield light prod. (%m)	Yield med prod. (%m)	Yield heavy prod. (%m)
11	Brent	37	0.32	7.49	22.5	37.3	40.2
22	Arabian Light	33.4	1.86	7.33	18.1	35.5	46.4
33	Arabian Heavy	27.9	2.69	7.08	15.5	29.9	54.6
44	Forcados	31	0.20	7.22	12.8	55.8	31.4
55	Condensate	> 50	< 0.10	8.10	67.7	32	0.3

2.3 Crude oil prices

The price of crude oil price which is processed in the refineries is a Custom-Insurance-Fret (CIF) price which is deduced from the Free On Board (FOB) price in two steps. First, we add a freight cost to the Free On Board (FOB) price. Second, we multiply this price by an insurance rate. Thus, the CIF price is expressed as follow:

CIF price = (FOB price + Freight cost) X (1 + insurance rate).

The freight cost is calculated according to a reference scale called "Worldscale". The Worldscale is a twice yearly publication which indicates, for all possible oil ports, a theoretical freight cost (in US dollar per tonne), which relates to the normal costs a "theoretically" perfect vessel for the purpose.

The freight rates are negociated for each voyage and they are expressed in terms of Worldscale. By definition, the base level of Worldscale is WS100. The freight rates are depending on both the quality of the product and the size of the tanker. They are reported in several publications such as the AFRA rates (Average Freight Rate Assessement). Two qualities of commodity are considered: "dirty" for crude oil and heavy fuel oil and "clean" for the other products (gasoline gas oil, etc.). Moreover, four main types of vessel are used for transporting categories of tankers should be used : the ULCC - Ultra Large Crude Carrier (325.000 - 600.000 dead-weight tonnage dwt), the VLCC - Very Large Crude Carrier (greater than 160.000 dwt) which is used for trips between the Persian Gulf and West or South East Asia, the Suezmax (between 100.000 and 160.000 dwt) which is capable of transiting the Suez canal fully loaded and the Aframax (between 80.000 and 100.000 dwt) which is used for regional traffic. For our purpose, the most relevant carrier type has been considered for each connexion. Finally, the freight costs are obtained by multiplying the Word scale reference costs by the freight rates.

We have tested the cointegration equilibrium between the five typical crude oil price. For this purpose, we have used monthly figures from 2002 to 2009. The unit root tests on the crude oil price series have been performed before the cointegration tests. All the series are integrated of order 1. We have established the long term equilibrium between the Brent price and the other crude oil prices :

Arabian Light =	0.94084155	BRENT	-11.4971798
	(0.0068587)		(2.90013518)

$R2= 0.996$
Period =2002.02 - 2008.05
n = 76

Arabian Heavy =	0.94359431	BRENT	-67.4735216
	(0.01164941)		(6.20121971)

$R2= 0.994$
Period =2005.01 - 2008.05
n = 41

Forcados =	1.00763715	BRENT	-9.70071618
	(0.00302721)		(1.27268544)

$R2= 0.999$
Period =2002.01 - 2008.05
n = 77

Condensate =	1.14220449	BRENT +	0.31462577
	(0.01956318)		(10.4138858)

$R2= 0.989$
Period =2005.01 - 2008.05
n = 41

2.4 Oil products

The oil product categories, which are considered in POLES, are liquefied petroleum products (LPG), gasoline and naphtha, middle distillates and heavy distillates. Naphtha is used as a raw material for petrochemicals as well as various special gasoline and solvents. Gasoline are split into different products depending upon octane numbers and lead contents ; middle distillates include kerosene (jet fuel), diesel oil and heating oil ; in the heavy products there are two heavy fuel oils with different sulphur contents (1% and 3.5%), and bitumen and petroleum coke. Furthermore, several qualities of marine bunker fuels have been considered in the new version of the OURSE model to apply the new rules of the International Maritime Organization (IMO) with a lower sulphur content for these fuels. More detailed on these new rules on emissions of air pollutants from international shipping which are regulated by the International Convention on the Prevention of Pollution from Ships called "MARPOL" (IMO, 2010) are given below and in the next section.

For the light products, in two cases the oil module requires a more detailed product breakdown than the demand module. First, propane and butane are distinguished in the LPG. Secondly, disparities in gasoline consumption between countries lead to distinguish five gasoline grades differing in their specifications. There is no quality control for liquefied petroleum gas and naphtha.

The five types of gasoline have to meet actual quality specifications such as specific gravity, vapour pressure, research and motor octane number and lead content. Aromatic, olefin and oxygen contents are also considered for the future and/or investigated specifications of gasoline. In the current version of the model, the most recent specification of the automotive fuels have been introduced (new rules in 2009 for the sulphur content of gasoline and diesel oil in Europe).

The middle distillates and the heavy fuel oils are subject to quality constraints as specific gravity, sulphur content, pour point and viscosity and diesel oil has to meet a minimum cetane number. As it has be done for gasoline, four diesel oil qualities have been distinguished.

This new version of the OURSE model considers the marine bunker fuel specifications in accordance with the new rules of the International Maritime Organization (IMO) which should be applied in the near future. The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI deals with the air pollution since 1997. The last revision of these international rules which seek to minimize airborne emissions from ships was adopted in October 2008 and entered into force in July 2010. Furthermore MARPOL is more restrictive in certain sea areas for environmental reasons. Consequently, the sea areas have to be distinguished between the Emission Control Areas (ECA) - Baltic Sea, North Sea and North America – and the other seas areas. For the SECA (Sulphur Emission Controlled Areas), the sulphur decrease will be: 0.1% sulphur content (1% 2010, 0.1% 2015); for the rest of the World, this will be: 0.5% sulphur content (now 4.5%, 3.5% 2012, 0.5% 2020).

Nevertheless, there is no such detailed distinction between the oil products on the demand side. Consequently, the oil products have been classified according to two nomenclatures (cf. Annex 2) :

- (1) General nomenclature which reflect the main product's families. This definition is used for the oil product demand.
- (2) Refineries nomenclature which is used inside the LP model

The oil product demand is split from the general definition (1) to the LP refining model oil product definition (2) through translation tables (cf Annex 2).

In the following table, the Worldwide oil product demand which was addressed to the refining industry in 2005 is summarized.

Table 2.4.1 – Oil product demand addressed to the refining industry 2005

Mt/year	North Am.	Latin Am.	North Europe	South Europe	CIS	Africa	M.East	China	Asia P	Total
LPG	63	15	18	13	9	10	12	20	45	**206**
Naphtha	21	8	33	8	0	1	9	30	90	**201**
Gasoline	454	40	87	36	39	31	52	48	125	**912**
Jet fuel	93	9	42	15	13	8	11	14	41	**245**
Other Kerosene	5	1	5	0	0	6	9	2	52	**81**
Heating oil	93	27	83	32	21	26	37	65	97	**482**
Diesel oil	170	51	130	73	20	28	40	49	130	**690**
Heavy fuel oil	66	21	24	36	29	21	54	34	88	**372**
Lubricants	9	2	5	2	4	2	1	7	8	**40**
Bitumen	37	3	14	9	7	3	5	7	15	**100**
Petroleum Coke	24	7	7	11	1	0	1	8	10	**69**
Marine Bunkers	21	8	33	14	0	5	14	12	45	**151**
Total	**1055**	**193**	**482**	**249**	**143**	**142**	**243**	**298**	**745**	**3549**
Share	**30%**	**5%**	**14%**	**7%**	**4%**	**4%**	**7%**	**8%**	**21%**	**100%**

Unit : million of tons
Source : IEA , BP Stats

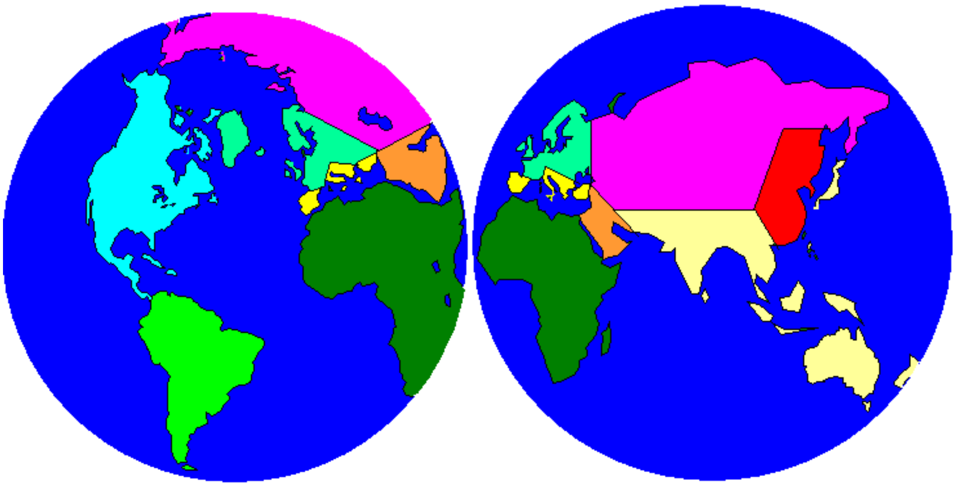
2.5 Geographical areas

As the model permits exchanges of petroleum products between the main regions in the world, the refining industry has been split into several geographical areas. However we have considered refining areas rather than the 184 "POLES" countries and regions in order to reduce the size of the LP model and to be in accordance with some of the previous hypothesis which are only valid for aggregate refining structures. Thus, in each refining area, we can assume that the crude oils are processed together and that there is only one investment variable for each unit. Moreover the model implicitly allows intermediate product exchanges inside each area.

The geographical considerations upon crude oil supply and petroleum product demand, and the technical analysis of the refineries lead to nine refining areas being defined in the world:

- Z1 North and Central America : Canada, USA, Mexico
- Z2 Latin America,
- Z3 North Europe
- Z4 South Europe and Turkey
- Z5 Former Soviet Union (CIS)
- Z6 Africa
- Z7 Middle East
- Z8 China
- Z9 Other Asia

Figure 4 – The OURSE refining areas



The correspondence between the POLES countries and the OURSE region is given in the Annex 3. The general denominations "Latin America", "Former Soviet Union", "Africa", "Middle East" are those which are used by the International Energy Agency (IEA) in its statistical yearbooks (energy balances).

2.6 Marginal cost pricing

The marginal costs associated to the demand equations are used to analyze the evolution of the product's prices. For a joint products industry such as refining industry, there is no single key to the breakdown of the total processing cost by products. But, under some assumptions derived from LP models, duality theory leads to marginal costs corresponding to average costs. At the equilibrium indeed the sum of the products of the marginal costs by the associated right-hand-side coefficients of primal constraints is equal under some assumptions to the global processing cost (objective function of the primal problem): this means that the valorization of refined products to their marginal costs corresponds to an income equal to overall costs introduced into the model. This result depends on one necessary condition: only the right-hand-side coefficients of demand constraints must be non-zero. Only long-term planning models fulfil this condition since the capacities of the refineries are variables of the problem and are not subsequently limited.

If we take the following notations :

$cost_j$: purchase and processing cost of crude oil j
$crude\ oil_j$: quantity of processed crude oil j
$Demand_i$: demand of product $_i$
λ_i : shadow value associated to the demand constraint for oil product i

Then, the primal objective function is :

$$\min \sum \cos t_j \times crudeoil_i$$

with a set of demand constraints with non null right-hand side :

Production $\geq$ Demand

then, the objective function of the dual problem is :

$$\max \sum \lambda_i \times Demand_i$$

Consequently, at the optimum (if the problem is feasible) :

$$\sum \cos t_j \times crudeoil_i^* = \sum \lambda_i^* Demand_i$$

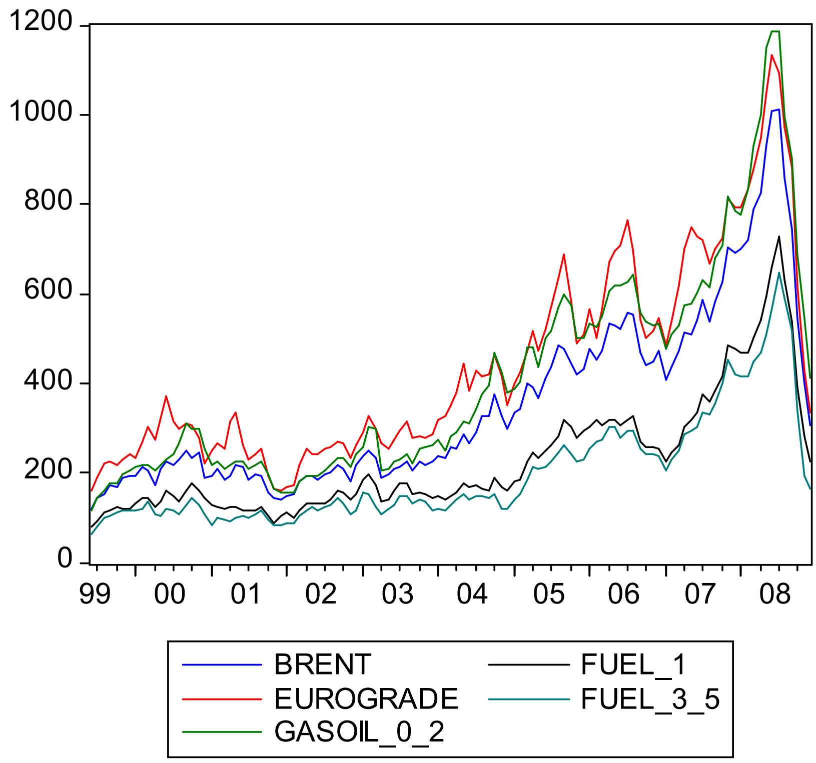
Consequently, the equilibrium between the oil product prices and the crude oil price corresponds to the equilibrium between the marginal cost of the oil products and the crude oil price. Thus, an analysis of the oil product market behaviour could be done through the study of the marginal costs.

We carry out an econometric analysis of the relationship between the crude oil price and the oil product prices on the three mail oil markets – Rotterdam, Nymex and Singapore – to compare the oil price relationships with the marginal cost pricing.

2.6.1 The Rotterdam market

We select three major products which are traded : a light product (Premium gasoline Eurograde 95), a middle distillate (gas oil 0.2% Sulphur) and an heavy product (heavy fuel oil 1% Sulphur). The crude oil price is the dated Brent price. We use monthly figures from 1999 to 2008 (figure 5).

Figure 5 – Brent and oil product prices on the Rotterdam market



We study the long term equilibrium between each oil product price and the crude oil price. We could not reject the hypothesis of three relationships between the prices (Table 2.6.1)

Table 2.6.1 – Cointegration tests on the Rotterdam market

		Trace test		
Hyp.	Eigenvalue	Trace Statistics	Critical value 0.05	Prob
r=0	0.3114	70.174	40.175	0.000
r ≤1	0.1286	28.018	24.276	0.016
r ≤2	0.094	12.460	12.321	0.047
r ≤3	0.011	1.309	4.130	0.295

After scaling the cointegrating vectors, the oil product prices could be expressed as a function of the crude oil price (Table 2.6.2). The econometric equilibrium between the oil products prices and the crude oil price are around 1.3 for premium (eurosuper 95) and gas oil. It stands at 0.6 for heavy fuel oil (1% sulphur). Because the refining industry is a joint product industry, the empirical values of the coefficients are greater than one for premium and gas oil and lower than one for heavy fuel oil (residual fuel oil).

The estimated coefficients are close to the ratio between the marginal cost of the oil product (from the LP model) and the crude oil price.

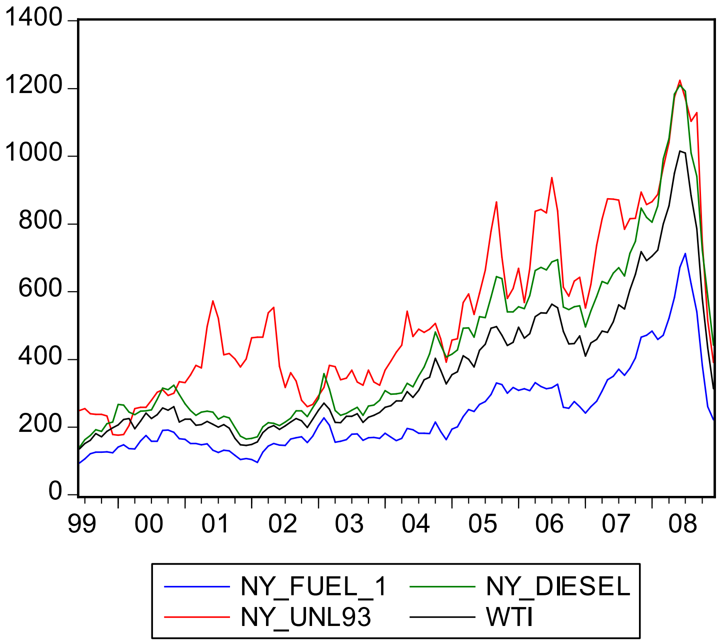
Table 2.6.2 – Long term equilibrium between prices on the Rotterdam market

NWE_EUROGRADE =	1.210 (0.027)	BRENT
NWE_GASOIL_0_2 =	1.171 (0.009)	BRENT
NWE_FUEL1 =	0.643 (0.016)	BRENT

2.6.2 The Nymex market

As for the Rotterdam market, we select three major products which are traded : a light product (Regular unleaded gasoline, NY_UNL93), a middle distillate (Diesel oil n°2, NY_DIESEL) and an heavy product (heavy fuel oil n°6 1% Sulphur, NY_FUEL_1). The crude oil price is the WTI price. We use monthly figures from 1999 to 2008 (figure 6).

Figure 6 – WTI and oil product prices on the Nymex market



Unit : US$/t
Source : Platts

We study the long term equilibrium between each oil product price and the crude oil price. We could not reject the hypothesis of three relationships between the prices (Table 2.6.3)

Table 2.6.3 – Cointegration tests on the Nymex market

		Trace test		
Hyp.	Eigenvalue	Trace Statistics	Critical value 0.05	Prob
r=0	0.304	77.846	54.079	0.000
r ≤1	0.147	39.115	35.193	0.018
r ≤2	0.115	22.045	20.262	0.028
r ≤3	0.080	8.960	9.164	0.055

After scaling the cointegrating vectors, the oil product prices could be expressed as a function of the crude oil price (Table 2.6.4). The econometric equilibrium between the oil products prices and the crude oil price are around 1.4 for regular gasoline (NY_UNL93), 1.3 for gas oil. It stands at 0.5 for heavy fuel oil (1% sulphur).

As for the Rotterdam market, the estimated value of the coefficients are close to the ratio between the marginal cost of the oil product (from the LP model) and the crude oil price. Subsequently, the coefficients have the same order of magnitude than the estimated coefficients on the Rotterdam market. The highest value for gasoline point out the tension on the North American market.

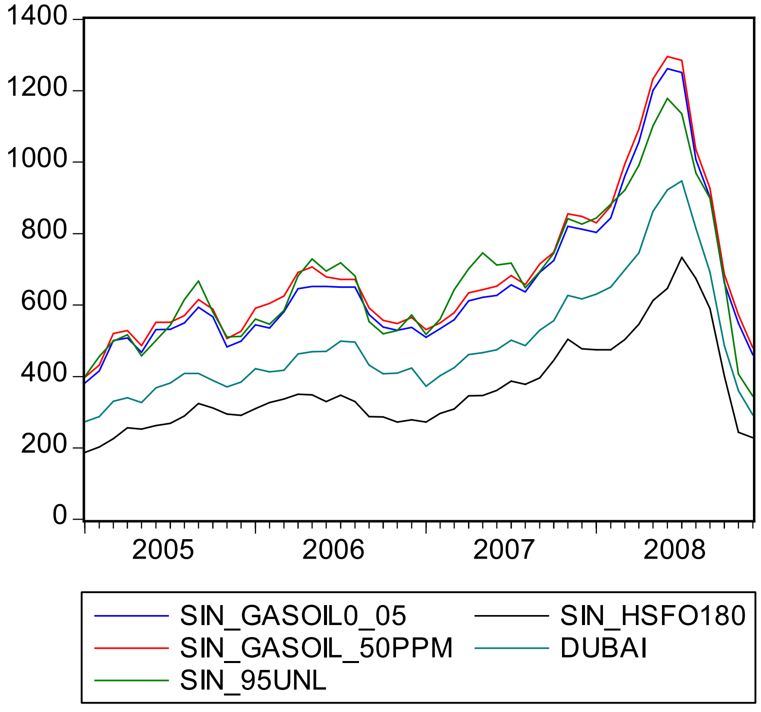
Table 2.6.4 – Long term equilibrium between prices on the Nymex market

NY_UNL93 =	+ 66.567	+ 1.4127WTI
	(62.658)	(0.173)
NY_DIESEL =	- 28.150	+ 1.2852WTI
	(6.5219)	(0.018)
NY_FUEL_1 =	+ 38.431	+ 0.4868WTI
	(17.040)	(0.047)

2.6.3 The Singapore market

As for the European and the North American markets, we select three major products which are traded : a light product (Motor gas 95 Unleaded, SIN_95UNL), a middle distillate (Gasoil 0.05% sulphur, SIN_GASOIL0_05 and Gasoil 50ppm, SIN_GASOIL_50ppm) and an heavy product (heavy fuel 3.5% souffre (maximum), 180 centistoke, SIN_FUEL180). The crude oil price is the Dubaï price. We use monthly figures from 2005 to 2008 (figure 7).

Figure 7 – Dubai and oil product prices on the Singapore market



Unit : US$/t - Source : Platts

We study the long term equilibrium between each oil product price and the crude oil price. The growing Asian demand and the improvement of the oil product specifications (increasing demand for 50ppm gas oil) leads to study each market independently (Engle and Granger approach, assessing the stability of the cointegration relationships with the Gregory and Hansen test). Finally, we obtain three long term equilibrium between each product (gasoline SIN_95UNL, gas oil SIN_GASOIL_50PPM, heavy fuel oil SIN_HSFO180) and the Dubai price (Tables 2.6.5 to 2.6.7).
As for the European and the North American markets, the estimated value of the coefficients are close to the ratio between the marginal cost of the oil product (from the LP model) and the crude oil price.

Table 2.6.5 – Long term equilibrium between gasoline price and crude oil on the Singapore market

SIN_95UNL =	102.352	+ 1.160 DUBAI
	(21.126)	(0.040)
R^2 =	0.946	
N =	48	(period 2005.01 – 2008.12)
DW =	0.659	

Table 2.6.6 – Long term equilibrium between gas oil price and crude oil on the Singapore market

SIN_GASOIL_50PPM =	- 50.494	+ 1.302 DUBAI
	(14.969)	(0.029)
R^2 =	0.978	
N =	48	(period 2005.01 – 2008.12)
DW =	0.724	

Table 2.6.7 – Long term equilibrium between heavy fuel oil price and crude oil on the Singapore market

SIN_HSFO180 =	-23.649	+ 0.797 DUBAI	– 65.189 Dummy0806
	(11.631)	(0.023)	(25.847)
R^2 =	0.967		
N =	48	(period 2005.01 – 2008.12)	
DW =	0.784		

nb: Dummy0806 is a dummy variable which is set to 1 for 06/2008 and 0 otherwise.

2.6.4 Equilibrium between the oil product prices

The international trade flows of oil products in the OURSE model are derived from the equilibrium between the marginal costs when a product is export from a refining area to an other market place. The possible international trade flows have been defined according to the observed flows of products.

If we note λ_1 and λ_2 the marginal costs of a given product in areas Z_1 and Z_2, the switch of solution when there is only one transportation variable only depends on the transportation cost (CT) .

$$\lambda_1 = \lambda_2 + CT$$

We carry out several econometric tests to validate this approach. For this purpose, we test the long term equilibrium between prices when there is an international flows of product. In the following example, we establish a relationship between the gasoline price in North America (NY_UNL93) and the gasoline price in Europe (NWE_Eurograde). The slope is close to 1 and the intercept is close to the transportation cost between North West Europe and the East Cost (of North America) for the clean products.

NY_UNL93 =	34.469 (11.665)	+ 1.098 NWE_EUROGRADE (0.019)
R^2 =	0.981	
N =	61	(period 2003.06 – 2008.06)
DW =	0.767	

3. Simulation of the OURSE model with the PRIMES oil product demand

The objective of the simulation is to run the OURSE worldwide refining model according to a set of assumption provided by the European Commission concerning the oil product demand (simulation obtained with the Primes model) and several assumptions concerning the oil product specifications for 2030.

According to the Primes simulation, the European oil product demand should decrease by 13.8% from 2005 to 2030 with a higher share of medium distillates and some more restrictive specifications on fuels. During the same time, the worldwide oil demand should increase of 23%. On the supply side, the refineries crude oil supply should reach 95.1 millions of barrels per day (Mbd) with a higher share of extra-heavy oil and condensates. Consequently, the refineries activity should be strongly affected by these evolutions. The model results - refinery throughput, investments, international trade flows – point out the very different trends of this industry in the main regions of the World.

This section is organized as follows: We present the oil product demand scenario of PRIMES/European Commission (reference scenario) and the global evolution of the worldwide oil demand in the next section, the second section is dedicated to the crude oil supply and the results of the simulation are analyzed in the following sections. Then, the results of the simulation area analyzed in section 3.3.

In order to assess the consequences of several hypotheses on the oil product demand, some other results are presented. Thus, the results of the OURSE model without improved quality of the marine bunker fuel are analyzed in section 3.4. Then, the intermediate results for 2020 are given in section 3.5. The other PRIMES energy scenario, namely baseline scenario, is also investigated. As described in the next paragraph, the baseline is a "business as usual" scenario. In this scenario, the oil demand highest than the oil demand in the Reference scenario. The results of the OURSE with the PRIMES baseline scenario for 2030 are presented in section 3.6 and 3.7 (with and without new marine bunker specifications). Then, the intermediate results for 2020 are given in section 3.8.
Finally, a sensitivity analysis on the crude oil supply is carried out with the PRIMES reference scenario for 2030 in section 3.9

3.1 Oil product demand

The oil product demand which is considered in the modelling approach is the final oil product demand and the demand for electricity generation. In the model, the refining industry has to reach this demand in quantity term and according to the product specifications. Note, that the bio fuel share of the automotive fuel consumption (gasoline and diesel oil) is deduced from the final demand.

Thus, according to the PRIMES simulations, the oil product demand which is addressed to the refining industry has been derived (table 3.1.1 in TOE and table 3.1.2 in metric tonnes).

The European oil product demand is decreasing of 13.8% over the period 2005-2030. The share of the different products have a slow evolution during this period: gasoline stands between 16% and 17% of the total oil product demand whilst the diesel oil share increases from 28% to 30.6%.

In the PRIMES simulations, two scenarios are considered : a "baseline" scenario and a "reference" scenario. The baseline scenario is a business as usual scenario whilst the reference scenario includes policies adopted in 2009 on renewable energy and GHG emissions (European Commission, 2010). The reference oil demand forecast for 2030 are 16.5 Mtoe lower than the baseline demand forecast (-8 Mtoe for heating oil and -6.2 Mtoe for diesel oil).

Table 3.1.1 – European oil product demand (TOE) –reference scenario

	2005	2010	2015	2020	2025	2030
LPG	27.2	29.0	29.9	29.3	28.2	27.4
Naphtha	46.2	42.9	43.2	42.3	42.0	41.0
Gasoline	115.6	105.0	101.1	96.4	93.8	91.7
Jet Fuel	49.7	52.0	58.2	63.6	66.5	66.5
Oth. Kerosene	6.2	2.3	2.2	2.1	1.9	1.7
Heating oil	106.1	98.7	93.4	84.3	78.3	73.5
Gas oil	182.9	188.4	195.3	188.3	185.0	173.6
Heavy Fuel Oil	49.0	27.0	22.1	16.1	13.6	11.5
Lubricant	5.9	5.6	6.0	6.2	6.3	6.5
Bitimen	19.1	18.1	19.3	20.0	20.3	20.9
Pet. Coke	5.9	5.6	6.0	6.2	6.3	6.5
Mar. Bunker	43.5	42.2	43.6	44.0	44.7	45.7
Total	657.2	616.8	620.3	598.8	586.8	566.4

Unit : million of TOE

Table 3.1.2 - European oil product demand (metric tons) –reference scenario

	Conv. factor	2005	2010	2015	2020	2025	2030
LPG	1.095	24.8	26.5	27.3	26.7	25.8	25.0
Naphtha	1.048	44.1	40.9	41.2	40.4	40.1	39.1
Gasoline	1.048	110.3	100.2	96.5	92.0	89.5	87.5
Jet Fuel	1.048	47.4	49.6	55.5	60.7	63.5	63.4
Oth. Kerosene	1.048	5.9	2.2	2.1	2.0	1.8	1.6
Heating oil	1	106.1	98.7	93.4	84.3	78.3	73.5
Gas oil	1	182.9	188.4	195.3	188.3	185.0	173.6
Heavy Fuel Oil	0.952	51.4	28.3	23.2	16.9	14.2	12.1
Lubricant	0.952	6.2	5.9	6.3	6.5	6.6	6.8
Bitumen	0.952	20.0	19.0	20.3	21.0	21.4	21.9
Pet. Coke	0.762	7.7	7.3	7.9	8.1	8.3	8.5
Mar. Bunker	0.952	45.7	44.3	45.8	46.2	46.9	48.0
Total		652.6	611.4	614.8	593.2	581.2	561.1

Unit : million of tons

nb : the conversion factors between tonne of oil equivalent and metric tonne are the ratio between the specific net calorific values of the products and the crude oil.

Note that the underlying hypothesis of this automotive fuel projection is that the European car sales will likely be less oriented to diesel engine as it is since 2000 (impact of Euro 6 implementation and economic crisis of the share between the different segments of vehicles observed in 2009). Another key assumption of Primes results is the very low decrease of heating oil demand.

Finally, this demand has been introduced in the worldwide oil demand simulation (Table 3.1.3 and Table 3.1.4). This projection which has been carried out by IFP. According to this simulation, the global oil demand will have a 23% increase from 2005 to 2030. Consequently, the share of Europe in the Worldwide demand will decrease from 20% of the worldwide demand in 2005 to around 14.2% in 2030.

Table 3.1.3 – Worldwide oil product demand – 2030 (TOE)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Total
LPG	64.2	15.2	18.7	14.7	12.8	24.1	33.1	36.7	61.2	280.7
NPH	20.6	12.4	34.4	8.1	21.7	1.3	28.4	107.6	119.4	354.1
GSL	318.4	64.4	72.1	36.3	60.3	59.4	118.5	160.8	238.6	1128.8
JET	108.8	14.9	51.6	19.4	30.9	19.1	27.5	120.7	92.8	485.7
KRS	2.1	1.0	1.6	0.1	0.4	6.7	6.3	1.9	23.7	43.7
HTO	75.8	31.6	57.9	24.7	22.6	35.4	34.7	89.3	120.9	492.7
GDO	201.3	87.2	117.8	69.1	32.7	59.4	104.5	113.1	176.4	961.5
RFO	15.1	13.7	5.2	8.6	24.4	11.8	21.4	19.6	31.4	151.0
LUB	5.3	2.4	5.2	2.9	7.1	1.4	1.4	16.3	18.4	60.4
BTM	22.7	5.0	14.1	10.6	16.3	2.8	17.7	18.8	27.0	135.0
CKP	30.2	6.6	1.4	5.6	0.8	0.5	0.9	9.1	11.3	66.4
MAB	31.8	14.1	33.0	14.4	20.7	12.1	28.3	21.5	76.0	251.8
Total	896.3	268.4	413.1	214.6	250.6	234.0	422.6	715.3	997.0	4411.8

Unit : million ot TOE

Table 3.1.4 – Worldwide oil product demand – 2030 (Tons)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	**Total**
LPG	58.6	13.8	17.1	13.5	11.7	22.0	30.2	33.5	55.9	256.3
NPH	19.7	11.8	32.8	7.8	20.7	1.3	27.1	102.7	114.0	337.8
GSL	303.8	61.4	68.8	34.6	57.6	56.7	113.1	153.5	227.7	1077.1
JET	103.8	14.3	49.2	18.5	29.5	18.2	26.2	115.2	88.6	463.4
KRS	2.0	1.0	1.5	0.1	0.4	6.4	6.0	1.8	22.6	41.7
HTO	75.8	31.6	57.9	24.7	22.6	35.4	34.7	89.3	120.9	492.7
GDO	201.3	87.2	117.8	69.1	32.7	59.4	104.5	113.1	176.4	961.5
RFO	15.9	14.4	5.4	9.0	25.6	12.4	22.4	20.6	32.9	158.6
LUB	5.5	2.6	5.5	3.1	7.5	1.4	1.5	17.2	19.3	63.5
BTM	23.9	5.3	14.8	11.1	17.1	2.9	18.6	19.7	28.3	141.8
CKP	39.6	8.6	1.9	7.4	1.1	0.7	1.1	11.9	14.8	87.2
MAB	33.4	14.8	34.7	15.1	21.7	12.7	29.8	22.6	79.8	264.5
Total	883.3	266.7	407.5	213.9	248.1	229.5	415.2	700.9	981.2	4346.2

Unit : million of tons

where LPG stands for Liquefied Petroleum Gas, NPH Naphtha, GSL Gasoline, JET Jet Fuel, KRS Other Kerosene, HTO Heating Oil, GDO Gas Oil, RFO Heavy Fuel Oil, LUB Lubricant, Bitumen, CKP Petroleum Coke, MAB Marine Bunker,

The main evolutions of the oil product specification up to 2030 are described below:

Gasoline: the sulphur content is 10 ppm (30 ppm in 2005 for the USA) and the aromatic content 35% vol... The specifications Euro IV and then Euro V will be adopted and this will be the same for the most industrialized cities in Asia.

Diesel oil: the sulphur content is 15 ppm in the USA (500 ppm in 2005 for the USA) and 10 ppm in Europe. The cetane index will grow up to 46 in the USA (40 in 2005). The specifications Euro IV and then Euro V will be adopted and this will be the same for the most industrialized cities in Asia.

Heavy fuel oil: the SO_2 emission will be limited to 600 mg/Nm3 in the industrialized countries. This hypothesis is introduced in the refining model through a constraint on the SO_2 emission of the refinery fuel and the other SO_2 emission of the refineries.

Marine bunkers: The new rules of the International Maritime Organization (IMO) will be applied. For the SECA (as defined in paragraph 2.4), the sulphur decrease will be: 0.1% sulphur content (1% 2010, 0.1% 2015); for the rest of the World, this will be: 0.5% sulphur content (now 4.5%, 3.5% 2012, 0.5% 2020). A set of the results without any change of the marine bunker specifications after 2012 is also presented.

3.2. Crude oil supply and prices

The crude oil supply has been extrapolated until 2030 for the nine main categories of crude oil considered in the model. This analysis is based on IFP geosciences expertises. In 2030, the API degree of the conventional crude oil will slowly decrease (-1.1°). However, this will be balanced by the increasing share of condensates in the refinery supply and the availability of upgraded crude oil from the extra-heavy oil.
Consequently, the average crude oil API degree should stand to around 34-35° with a 1.25% sulphur content (Table 2.1).

Table 3.2.1 – Crude oil supply

	2005			2030		
	Volume	API degree	Suphur %	Volume	API degree	Suphur %
Conventional crude oil	73.30	31.60	1.30	78.80	30.50	1.67
Extra Heavy Oil (before upgrading)	1.90			7.20		
Condensate & LPG	6.70			9.80		
Total	81.90	33.30	1.24	95.80	32.70	1.57
Losses in upgraders (incl. petcoke)	-0.20			-0.70		
Refineries supply	**81.70**	**33.90**	**1.15**	**95.10**	**34.70**	**1.25**
CTL GTL	0.23			1.77		

Unit : Mbd

According to the PRIMES simulations, the reference crude oil price which is considered in the model raises up to 105.9 $/b in 2030 (Table 2.2).

Table 3.2.2 – Crude oil price assumption for the PRIMES scenario (DG-Tren)

	2010	2020	2030
Global crude oil price, in 2008 prices, $	71.9	88.4	105.9

3.3. Results of the simulation 2030 with the PRIMES reference scenario

3.3.1 Refineries throughput

The production of the refineries has been, classically, split in light, medium and heavy products (table 3.3.1 and 3.3.2). The refineries production decreases in North America and in Europe whilst it strongly increases in the other regions of the World. The EU-27 production is reduced to around 577 Mtoe in 2030 (co Table 3.3.5), i.e. 573 Mt. The production was 666.2 Mt in 2005 and 652.4 Mt in 2008. Thus, the European production should represents 14% lower than the 2005 production which is the same evolution than the oil product demand.

Table 3.3.1 Production of the refineries (TOE)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	371.0	103.6	124.8	61.2	106.7	87.1	177.5	293.8	372.2
Medium	387.9	134.7	197.1	105.0	132.1	119.6	186.6	309.2	411.2
Heavy	100.4	46.5	59.4	43.1	69.3	28.6	70.4	85.3	163.9
TOTAL	859.4	284.8	381.3	209.3	308.1	235.4	434.5	688.3	947.3

Unit : million of TOE

Table 3.3.2 Production of the refineries (metric tons)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	352.1	98.2	118.5	58.0	101.3	82.4	168.2	279.2	353.4
Medium	382.9	134.0	194.7	104.1	130.4	118.5	184.4	304.3	405.9
Heavy	113.4	50.5	63.2	46.7	73.0	30.2	74.4	91.9	175.2
TOTAL	848.4	282.8	376.3	208.8	304.7	231.0	427.0	675.5	934.5

Unit : million of tons

3.3.2 Crude oil supply

The crude oil supply of the refineries will grow up to 4508 million of tons which is 21% higher than the 2005 supply. However, the API degree (35.1) and the sulphur content (1.50%) simulated for 2030 are close to the 2005 values.

Table 3.3 – Crude oil supply of the refineries

		2005			2030		
Area		Quantity	API	Sulphur %	Quantity	API	Sulphur %
Z1	North Am.	1075.6	34.6	1.49	889.4	36.3	1.52
Z2	Latin Am.	215.3	31.2	1.71	300.9	28.6	1.70
Z3	North Eur.	487.3	33.7	1.24	393.9	33.6	1.29
Z4	South Eur.	244.6	32.4	1.51	220.5	32.3	1.43
Z5	CIS	274.8	31.6	2.08	314.8	33.6	1.50
Z6	Africa	140.7	38.6	0.76	246.6	37.0	0.46
Z7	Midle East	280.4	31.1	2.15	449.9	32.6	1.86
Z8	China	266.8	39.4	0.82	706.2	38.3	1.46
Z9	Asia & Pac.	738.6	37.2	1.61	986.2	35.9	1.62
Total		**3724.2**	**34.7**	**1.51**	**4508.4**	**35.1**	**1.50**

Unit: million of ton

3.3 Main flows of products and balance of the European Union

The trade flows of oil products point out the needs of gasoline of North America and the needs of diesel oil of Europe (Table 3.3.4). The CIS refineries have enough refining capacities to export some products in Western Europe as well as in Asia.

However, other analysis of such trade flows is that the processing capacities are depending on foreign demand which could fluctuate. This is in particular the case for the production of gasoline in Europe which could be durably allocated by a decline of the exports towards the American market as it was observed since the recent economic crisis.

The simulation of the oil product balance for EU-27 point out that the global production and consumption are in equilibrium. However, there are some important flows of diesel oil imports (around

21% of the demand) and the European refineries exports around 18% of its gasoline production (Table 3.3.5).

Consequently, if the part of the diesel in the consumption of fuel is more raised han in the PRIMES projections in the next years, then it will be more difficult for the European refineries to answer this demand. Higher imports will then be to envisage (this for a given level of demand of heating oil).

Moreover, some larger quantities of gasoline from the European refineries should find foreign markets (which is not obvious).

Table 3.3.4 Trade flows of oil products

Light

		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
FROM ↓	TO →	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.
Z1	North Am.									
Z2	Latin Am.									11.7
Z3	North Eur.					4.4				
Z4	South Eur.	5.8				0.8				
Z5	CIS									17.1
Z6	Africa	8.5								
Z7	Midle East								1.5	
Z8	China									
Z9	Asia & Pac.									

Medium

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	North Am.									
Z2	Latin Am.									
Z3	North Eur.									
Z4	South Eur.									
Z5	CIS			31.7	8.3				3.0	2.6
Z6	Africa									
Z7	Midle East						0.8		12.8	
Z8	China									
Z9	Asia & Pac.									

Heavy

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	North Am.									
Z2	Latin Am.	4.7								
Z3	North Eur.									
Z4	South Eur.									
Z5	CIS									
Z6	Africa									
Z7	Midle East									
Z8	China									
Z9	Asia & Pac.									

Unit : million of TOE

Table 3.3.5 – Simulation of the oil product balance of the European Union in 2030

	Production	Imports	Consumption	Exports
LPG	27.4	0.0	27.4	0.0
Naphtha	40.2	0.8	41.0	0.0
Gasoline	111.0	0.0	91.7	19.4
Jet Fuel	68.1	0.0	66.5	1.7
Oth. Kerosene	1.8	0.0	1.7	0.0
Heating oil	75.6	0.0	73.5	2.0
Gas oil	135.9	37.7	173.6	0.0
Heavy Fuel Oil	14.1	0.0	11.5	2.6
Lubricant	6.5	0.0	6.5	0.0
Bitumen	20.9	0.0	20.9	0.0
Pet. Coke	12.1	0.0	6.5	5.7
Mar. Bunker	45.7	0.0	45.7	0.0
Total	559.3	38.5	566.4	31.4

Unit : million of TOE

3.3.4 Refining capacities

The following table (Table 3.3.6) shows the rate of use of the processing units compared to the calibration date (baseline 100 = 2005). **Thus the figures which are greater than 100% are investments.**

An other point is that no special features have been put on existing capacities in OECD countries like closure of certain refineries as it could be expected due to economic conditions.

Table 3.3.6 – Rate of use of the refining units (baseline 100=2005)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe
Topping	82.7%	139.8%	80.8%	90.2%	114.5%	175.3%	160.4%	264.7%	133.5%	84.0%
Cat. Reformer	68.5%	194.4%	63.0%	76.9%	105.6%	131.1%	136.6%	482.4%	135.0%	67.7%
FCC	55.1%	139.1%	82.5%	100.0%	124.0%	565.1%	448.2%	365.0%	201.7%	87.4%
RCC	100.0%	378.0%	100.0%			200.8%	541.0%	207.2%	182.3%	100.0%
CKR	90.0%	315.6%	196.7%	135.8%	77.0%		5071.4%	308.4%	214.9%	153.1%
HDS gas oil	160.3%	360.5%	156.9%	134.2%	116.2%		236.5%	422.4%	217.4%	147.7%
HCK 78%conv.			127.7%	100.0%			100.0%		100.0%	122.1%
HCK Full/Naphta/Jet	100.0%									
HDS residuals		43.1%	238.5%	92.4%		100.0%	152.0%	100.0%	118.8%	185.2%

The main investments concern the regional areas Z7 (Middle East), Z8 (China) and Z9 (Other Asia and Pacific) in order to reach the increasing demand (Table 3.3.7).

In Europe and North America, the slowdown of the demand affects the production of the refineries. Consequently, the rates of use of the topping units decrease (in the same proportion than the oil product demand). The low rate for Fluid Catalytic Crackers (FCC) is likely to be not acceptable by industry and could occur in shutdown of refineries. In Europe and North America, the slowdown of the demand affects the rate of use of the refining units. However, in Europe, some investments in essentially gasoil hydrodesulphurization units and at a lower level Vacuum Gas Oil (VGO)/residue hydrodesulphurization (for bunkers quality) and hydrocracking units (as the diesel oil share in the total automotive fuel consumption continue to increase slightly) are required .

Table 3.3.7 – Investments in refining (2005-2030)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8&Z9	
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
Topping unit & VDU		100.3				101.2	84.4	538.5	77.8		616.3	902.2
Reforming Unit & Isom.		20.5	0.6	4.7	8.1	6.9	18.1	83.3	55.2	5.3	138.5	197.3
FCC		15.6			7.9	44.5	58.8	35.7	45.9		81.7	208.4
RCC		16.4			24.4	2.5	43.7	35.6	45.4		81.0	167.9
Coker (CKR)		30.0	6.0	5.6		4.0	7.0	25.5	24.5	11.5	50.0	102.4
HDS gas oil	211.2	57.3	47.5	36.1	46.9	46.0	78.1	106.0	127.4	83.6	233.4	756.5
HDT vacuum gas oil	11.8	22.5	1.7	2.5	12.6		25.1	45.4	62.2	4.2	107.6	183.8
Hydrocraking (HCK)			6.6					77.1		6.6	77.1	83.7
HDS residuals			5.4				14.3		10.6	5.4	10.6	30.3
Claus		2.3	0.8	0.1	1.3	0.4	4.7	6.2	6.4	1.0	12.6	22.1
Hydrogene Units	1.8	2.2	2.2	0.6	1.7	0.6	2.0	10.0	4.0	2.8	14.0	25.1

Unit : million of ton/year

Note that the modelling approach does not take into account the availability of the engineering companies to build the new processing units over the period and the financial constraints of the companies for investments. Relating to the figures in the table 3.7, this issue should not be too difficult to cope with (around 50 to 90 refineries in 25 years to be built). Also, it should be more interesting to build them in the growing or emerging markets or in the oil producing countries rather than in the decreasing markets with some consequences on the international trade flows of products.

The following table gives an estimation of the investment costs requirements over the 25 years period 2005-2030. It should reach around 21 billion of dollars in Europe which represents 5.1% of the total investments of the worldwide refining sector.

Table 3.3.8 – Cost of investments in refining (2005-2030)

Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8 & Z9	
North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
25.1	36.8	13.6	6.5	20.0	23.2	52.8	119.3	80.9	20.1	200.3	378.2

Unit : G$

3.3.5 CO_2 Emissions

The CO_2 emissions are split between the emissions of the up graders and those from the refineries, stricto sensu (Table 3.9). The needs of hydrogen in the refineries contribute to increase the CO_2 emissions. The direct emission due to the hydrogen production could correspond to around 20% of the refineries emissions in 2030 (14% in 2005) as natural gas steam reforming should be he dominant technology. In addition contribution of the up-grading of extra heavy crude (Canada and Venezuela) will account for more than 13% in 2030 (4% in 2005).

Table 3.3.9 CO_2 Emission of the refineries

zone		Total	Upgraders	Refineries	Detail of the refineries : Processing units	Hydrogene prod.
Z1	North Am.	233.6	67.5	166.2	127.0	39.2
Z2	Latin Am.	90.6	40.1	50.5	43.3	7.2
Z3	North Eur.	66.7	0.0	66.7	50.0	16.7
Z4	South Eur.	34.0	0.0	34.0	27.3	6.7
Z5	CIS	40.5	0.0	40.5	33.4	7.1
Z6	Africa	34.7	0.0	34.7	32.6	2.0
Z7	Midle East	77.5	0.0	77.5	61.3	16.2
Z8	China	110.3	0.0	110.3	79.8	30.5
Z9	Asia & Pac.	146.0	0.0	146.0	110.5	35.5
Total		833.8	107.6	726.3	565.2	161.1

Unit : million of ton

3.3.6 Marginal costs

The following table gives the marginal cost for the most important products. The gasoline and the diesel oil marginal costs do not refer to the same product in all the regions of the World but they refer to the most "common" quality of gasoline (or diesel oil) in each region. According to a reference crude oil price of 105.9$/b (i.e. 794.25$/t) , the ratio gasoline/crude oil remains around 1.25 and the ratio diesel oil/crude oil is between 1.1 and 1.15 in most of the regions which means that they do not significantly change over the period.

However the ratio heavy fuel oil/crude oil grows up to 0.95 which clearly reflects the desulphurization cost of the products.

Table 3.3.10 Marginal cost

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Gasoline	999.8	983.8	974.6	973.8	989.8	931.6	1001.4	1043.3	1026.9
Diesel oil	865.5	900.6	895.0	895.0	825.1	867.3	831.2	792.2	851.4
Jet fuel	927.6	902.7	969.0	899.7	969.4	908.4	988.6	1159.5	1032.3
HFO 1%	766.5	739.8	720.6	746.0	754.1	759.9	728.7	742.4	752.0
Mar. Bunker 0.5%	781.0	749.6	738.6	757.8	772.2	769.1	746.6	759.1	770.5

Unit : US$/ton

3.4 Variant of the 2030 simulation – PRIMES reference scenario, without new marine bunker fuel specification

This simulation has been carried out without any change of marine bunker specifications after 2012 : 1% sulphur content in the SECA and 3.5% sulphur content in the other areas.

3.4.1 Refineries throughput

The production of the refineries has been, classically, split in light, medium and heavy products (table 3.4.1 and 3.4.2). The refineries production decreases in North America and in Europe whilst it strongly increase in the other regions of the World. The EU-27 production is reduced to around 571 Mtoe in 2030 (cf Table 3.4.5), i.e. 567 Mt. The production of the recent years was 666.2 Mt in 2005 and 652.4 Mt in 2008. Thus, the European production should represents 15% lower than the 2005 production which is the same evolution than the oil product demand.

Table 3.4.1 Production of the refineries (TOE)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	367.4	94.4	129.3	60.8	112.0	86.3	175.9	295.2	375.2
Medium	387.9	134.7	202.0	100.3	130.6	116.9	192.3	309.2	409.5
Heavy	103.1	43.7	67.6	43.1	69.3	16.6	72.9	87.9	161.3
TOTAL	858.5	272.8	398.9	204.2	311.9	219.7	441.1	692.3	946.0

Unit : million of TOE

Table 3.4.2 Production of the refineries (metric tons)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	348.7	89.4	122.8	57.6	106.5	81.6	166.7	280.5	356.3
Medium	382.9	134.0	199.6	99.5	129.0	115.7	190.0	304.3	404.3
Heavy	116.2	47.7	71.5	46.7	73.0	17.5	76.9	94.7	172.4
TOTAL	847.8	271.1	393.9	203.7	308.4	214.8	433.6	679.6	933.0

Unit : million of tons

3.4.2 Crude oil supply

The crude oil supply of the refineries will grow up to 4501 million of tons which is 20% higher than the 2005 supply. However, the API degree (34.6) and the sulphur content (1.4%) simulated for 2030 are close to the 2005 values.

Table 3.4.3 – Crude oil supply of the refineries

		2005			2030		
Area		Quantity	API	Sulphur %	Quantity	API	Sulphur %
Z1	North Am.	1075.6	34.6	1.49	887.0	36.1	1.51
Z2	Latin Am.	215.3	31.2	1.71	287.5	28.9	1.56
Z3	North Eur.	487.3	33.7	1.24	411.0	33.4	1.29
Z4	South Eur.	244.6	32.4	1.51	215.1	32.3	1.54
Z5	CIS	274.8	31.6	2.08	319.2	35.8	1.52
Z6	Africa	140.7	38.6	0.76	230.5	38.1	0.31
Z7	Midle East	280.4	31.1	2.15	456.1	33.0	1.66
Z8	China	266.8	39.4	0.82	709.9	38.3	1.52
Z9	Asia & Pac.	738.6	37.2	1.61	984.6	35.2	1.72
Total		**3724.2**	**34.7**	**1.51**	**4501.0**	**35.1**	**1.50**

Unit: million of ton

3.4.3 Main flows of products and balance of the European Union

The trade flows of oil products point out the needs of gasoline of North America and the needs of diesel oil of Europe (Table 3.4.4). The CIS refineries have enough refining capacities to export some products in Western Europe as well as in Asia.

Table 3.4.4 Trade flows of oil products

Light

FROM ↓	TO →	Z1 North Am.	Z2 Latin Am.	Z3 North Eur.	Z4 South Eur.	Z5 CIS	Z6 Africa	Z7 Midle East	Z8 China	Z9 Asia & Pac.
Z1	**North Am.**									
Z2	**Latin Am.**	0.6								1.9
Z3	**North Eur.**	3.2				5.2				
Z4	**South Eur.**	6.2								
Z5	**CIS**									24.5
Z6	**Africa**	7.6								
Z7	**Midle East**									
Z8	**China**									
Z9	**Asia & Pac.**									

Medium

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	**North Am.**									
Z2	**Latin Am.**									
Z3	**North Eur.**									
Z4	**South Eur.**									
Z5	**CIS**			26.8	12.9					4.3
Z6	**Africa**									
Z7	**Midle East**						3.6		15.7	
Z8	**China**									
Z9	**Asia & Pac.**									

Heavy

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	**North Am.**									
Z2	**Latin Am.**	1.9								
Z3	**North Eur.**						9.1			
Z4	**South Eur.**									
Z5	**CIS**									
Z6	**Africa**	0.1								
Z7	**Midle East**						3.0			
Z8	**China**									2.7
Z9	**Asia & Pac.**									

Unit : million of TOE

The simulation of the oil product balance for EU-27 point out that the global production and consumption are equilibrated. However, there are some important flows of diesel oil imports (around 21% of the demand) and the European refineries should export around 19% of its gasoline production (Table 3.4.5).

Table 3.4.5 – Simulation of the oil product balance of the European Union in 2030

	Production	Imports	Consumption	Exports
LPG	27.4	0.0	27.4	0.0
Naphtha	40.2	0.8	41.0	0.0
Gasoline	114.5	0.0	91.7	22.9
Jet Fuel	68.1	0.0	66.5	1.7
Oth. Kerosene	1.8	0.0	1.7	0.0
Heating oil	75.6	0.0	73.5	2.0
Gas oil	136.6	37.0	173.6	0.0
Heavy Fuel Oil	22.8	0.0	11.5	11.3
Lubricant	6.5	0.0	6.5	0.0
Bitimen	20.9	0.0	20.9	0.0
Pet. Coke	11.2	0.0	6.5	4.8
Mar. Bunker	45.7	0.0	45.7	0.0
Total	571.3	37.8	566.4	42.7

Unit : million of TOE

3.4.4 Refining capacities

The following table (Table 3.4.6) shows the rate of use of the processing units compared to the calibration date (baseline 100 = 2005). Thus the figures which are greater than 100% are investments.

An other point is that no special features has been put on existing capacities in OECD countries like closure of certain refineries as it could be expected due to economic conditions.

Table 3.4.6 – rate of use of the refining units (baseline 100=2005)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe
Topping	82.5%	133.5%	84.4%	88.0%	116.2%	163.8%	162.7%	266.0%	133.3%	85.6%
Cat. Reformer	66.2%	162.5%	64.2%	75.6%	104.5%	128.8%	153.9%	494.1%	133.5%	68.1%
FCC	57.4%	139.9%	89.2%	100.0%	100.0%	557.9%	484.0%	404.6%	213.3%	92.2%
RCC	100.0%	205.4%	100.0%			237.2%	468.2%	180.2%	209.7%	100.0%
CKR	90.0%	315.6%	196.7%	135.8%	77.0%		5071.4%	281.5%	230.3%	153.1%
HDS gas oil	160.3%	356.7%	166.8%	127.3%	119.8%		233.4%	418.8%	223.9%	150.8%
HCK 78%conv.			100.0%	100.0%		18.2%	100.0%		100.0%	100.0%
HCK Full/Naphta/Jet	100.0%		#DIV/0!							
HDS residuals		43.1%	100.0%	34.1%		100.0%	100.0%	100.0%	100.0%	75.9%

As for the previous run, the main investments concern the regional areas Z7 (Middle East), Z8 (China) and Z9 (Other Asia and Pacific) in order to reach the increasing demand (Table A5.7). In Europe and North America, the slowdown of the demand affects the production of the refineries.

Table 3.4.7 – Investments in refining (2005-2030)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8&Z9	
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
Topping unit & VDU		97.2				91.2	122.0	550.4	79.2		629.6	940.1
Reforming Unit & Isom.		16.0	0.7	4.4	10.1	6.4	18.8	86.2	51.4	5.1	137.6	194.0
FCC		15.9				43.8	64.8	41.1	51.2		92.3	216.8
RCC		6.2			25.0	3.4	36.4	26.6	60.5		87.1	158.2
Coker (CKR)		30.0	6.0	5.6		4.0	7.0	22.2	27.8	11.5	50.0	102.4
HDS gas oil	210.5	56.4	55.8	32.1	42.3	44.7	76.8	105.1	133.2	87.9	238.3	757.0
HDT vacuum gas oil	0.4	22.8			0.0		11.4	47.5	61.3		108.8	143.4
Hydrocraking (HCK)								78.2			78.2	78.2
HDS residuals												
Claus		1.2	0.0		0.7	0.2	2.9	5.9	5.0	0.0	10.9	15.9
Hydrogene Units	1.3	1.7	1.3	0.2	1.3	0.6		9.4	3.3	1.5	12.7	19.1

Unit : million of ton/year

The following table gives an estimation of the investment costs requirements over the 25 years period 2005-2030. It should reach around 16.5 billion of dollars in Europe which represents 4.1% of the total investments of the worldwide refining sector.

Table 3.4.8 – Cost of investments in refining (2005-2030)

Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8 & Z9	
North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
23.0	33.1	11.6	5.8	16.9	22.8	47.7	123.3	81.5	17.4	204.8	365.8

Unit : G$

3.4.5 CO_2 Emissions

The CO_2 emissions are split between the emissions of the upgraders and those from the refineries, stricto sensu (Table 3.4.9). Then the refineries emission are divided between the processing units and the hydrogen production which should stand for around 20% of the refineries emissions in 2030. The emissions are 3% lower than the emissions with the future IMO specification of bunker fuels (Table 3.3.9).

Table A6.9 CO_2 Emission of the refineries

zone		Total	Upgraders	Refineries	Detail of the refineries : Processing units	Hydrogene prod.
Z1	North Am.	230.5	67.5	163.0	125.2	37.7
Z2	Latin Am.	85.6	40.1	45.5	39.6	5.9
Z3	North Eur.	65.3	0.0	65.3	51.2	14.1
Z4	South Eur.	32.4	0.0	32.4	26.8	5.7
Z5	CIS	35.9	0.0	35.9	29.6	6.3
Z6	Africa	34.7	0.0	34.7	32.7	2.0
Z7	Midle East	72.6	0.0	72.6	62.0	10.6
Z8	China	109.0	0.0	109.0	80.3	28.7
Z9	Asia & Pac.	145.4	0.0	145.4	111.9	33.5
Total		811.4	107.6	703.9	559.3	144.5

Unit : million of ton

3.4.6 Marginal costs

According to a reference crude oil price of 105.9$/b (i.e. 794.25$/t) , the ratio gasoline/crude oil remains around 1.25 and the ratio diesel oil/crude oil is between 1.1 and 1.15 in most of the regions which means that we could say that they do not change over the period.

However the ratio heavy fuel oil/crude oil grows up to 0.95 which clearly reflects the desulphurization cost of the products.

Table 3.4.10 Marginal cost

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Gasoline	999.8	983.8	974.6	973.8	989.8	931.6	1001.4	1043.3	1026.9
Diesel oil	865.5	900.6	895.0	895.0	825.1	867.3	831.2	792.2	851.4
Jet fuel	927.6	902.7	969.0	899.7	969.4	908.4	988.6	1159.5	1032.3
HFO 1%	766.5	739.8	720.6	746.0	754.1	759.9	728.7	742.4	752.0

Unit : US$/ton

3.5. Results of the simulation with the PRIMES reference scenario : intermediate results for 2020

In the following paragraphs, the intermediate results for 2020 are presented. The hypotheses of oil price and oil product demand are given in section 3.2.

3.5.1 Refineries throughput

Table 3.5.1 Production of the refineries (TOE)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	436.9	79.4	140.5	65.9	95.0	68.5	136.3	208.9	341.6
Medium	378.3	116.2	214.5	109.4	119.1	100.0	156.8	232.1	374.1
Heavy	112.9	52.6	69.9	44.1	62.7	19.7	70.3	75.4	163.1
TOTAL	928.1	248.3	424.9	219.4	276.8	188.2	363.4	516.3	878.8

Unit : million of TOE

Table 3.5.2 Production of the refineries (metric tons)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	414.4	75.2	133.4	62.4	90.2	64.8	129.2	198.2	324.0
Medium	373.4	115.6	212.2	108.5	117.6	99.0	155.0	229.1	369.3
Heavy	126.5	56.7	74.0	47.8	66.1	20.8	74.1	80.9	174.5
TOTAL	914.3	247.5	419.5	218.7	273.9	184.5	358.3	508.2	867.8

Unit : million of tons

3.5.2 Crude oil supply

Table 3.5.3 – Crude oil supply of the refineries

		2005			2020		
Area		Quantity	API	Sulphur %	Quantity	API	Sulphur %
Z1	North Am.	1075.6	34.6	1.49	950.2	35.9	1.53
Z2	Latin Am.	215.3	31.2	1.71	265.6	29.0	1.61
Z3	North Eur.	487.3	33.7	1.24	438.6	33.7	1.26
Z4	South Eur.	244.6	32.4	1.51	232.2	31.9	1.48
Z5	CIS	274.8	31.6	2.08	283.1	34.2	1.58
Z6	Africa	140.7	38.6	0.76	197.8	37.2	0.34
Z7	Midle East	280.4	31.1	2.15	377.2	31.5	1.77
Z8	China	266.8	39.4	0.82	529.2	36.8	1.37
Z9	Asia & Pac.	738.6	37.2	1.61	907.1	34.5	1.78
Total		**3724.2**	**34.7**	**1.51**	**4181.0**	**34.4**	**1.51**

Unit: million of ton

3.5.3 Main flows of products and balance of the European Union

Table 3.5.4 Trade flows of oil products

Light		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
FROM ↓	**TO →**	**North Am.**	**Latin Am.**	**North Eur.**	**South Eur.**	**CIS**	**Africa**	**Midle East**	**China**	**Asia & Pac.**
Z1	**North Am.**									
Z2	**Latin Am.**	2.2								
Z3	**North Eur.**	5.9				5.2				
Z4	**South Eur.**	9.8								
Z5	**CIS**								11.8	11.9
Z6	**Africa**	4.6								
Z7	**Midle East**									
Z8	**China**									
Z9	**Asia & Pac.**									

Medium

FROM ↓	**TO →**	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**
Z1	**North Am.**									
Z2	**Latin Am.**									
Z3	**North Eur.**									
Z4	**South Eur.**									
Z5	**CIS**			30.9	5.6				5.4	3.4
Z6	**Africa**									
Z7	**Midle East**				3.4				10.3	
Z8	**China**									
Z9	**Asia & Pac.**									

Heavy

FROM ↓	**TO →**	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**
Z1	**North Am.**									
Z2	**Latin Am.**	13.0								
Z3	**North Eur.**						9.2			
Z4	**South Eur.**									
Z5	**CIS**									
Z6	**Africa**									
Z7	**Midle East**									
Z8	**China**									
Z9	**Asia & Pac.**									

Unit : million of TOE

Table 3.5.5 – Simulation of the oil product balance of the European Union in 2020

	Production	Imports	Consumption	Exports
LPG	29.3	0.0	29.3	0.0
Naphtha	41.4	1.0	42.3	0.0
Gasoline	123.4	0.0	96.4	27.0
Jet Fuel	65.2	0.0	63.6	1.6
Oth. Kerosene	2.1	0.0	2.1	0.0
Heating oil	85.6	0.0	84.3	1.3
Gas oil	149.0	39.3	188.3	0.0
Heavy Fuel Oil	27.5	0.0	16.1	11.5
Lubricant	6.2	0.0	6.2	0.0
Bitimen	20.0	0.0	20.0	0.0
Pet. Coke	10.7	0.0	6.2	4.6
Mar. Bunker	44.0	0.0	44.0	0.0
Total	604.5	40.2	598.8	45.9

Unit : million of TOE

3.5.4 Refining capacities

Table 3.5.6 – rate of use of the refining units (baseline 100=2005)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe
Topping	88.3%	123.4%	90.0%	95.0%	103.0%	140.6%	134.5%	198.3%	122.8%	91.7%
Cat. Reformer	95.4%	135.7%	76.2%	86.8%	100.0%	102.9%	128.2%	342.8%	123.4%	79.8%
FCC	59.4%	113.3%	87.2%	100.0%	100.0%	443.6%	381.1%	383.8%	197.7%	90.7%
RCC	100.0%	100.0%	100.0%			100.2%	368.3%	145.7%	154.2%	100.0%
CKR	90.0%	315.6%	196.7%	130.3%	83.2%		5071.4%	251.1%	247.9%	149.1%
HDS gas oil	152.4%	325.7%	172.5%	142.3%	106.6%		195.7%	353.2%	209.8%	160.3%
HCK 78%conv.			100.0%	100.0%		0.0%	100.0%		100.0%	100.0%
HCK Full/Naphta/Jet	100.0%									
HDS residuals		43.1%	100.0%	34.1%		92.8%	100.0%	100.0%	100.0%	75.9%

Table 3.5.7 – Investments in refining (2005-2030)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8&Z9	
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
Topping unit & VDU		69.5				44.9	18.1	273.6	0.9		274.5	406.9
Reforming Unit & Isom.	8.5	11.2	2.4	2.2	9.2	0.9	9.8	49.6	42.7	4.7	92.3	136.6
FCC		5.3				32.9	47.5	38.2	44.1		82.4	168.0
RCC					21.7	0.0	26.6	15.2	29.9		45.0	93.3
Coker (CKR)		30.0	6.0	4.7		4.0	7.0	18.5	31.5	10.7	50.0	101.6
HDS gas oil	197.6	49.6	60.5	40.7	37.3	38.9	60.8	88.7	120.7	101.2	209.4	694.8
HDT vacuum gas oil	0.6	6.5			0.0		9.9	48.7	54.0		102.7	119.8
Hydrocraking (HCK)								7.5			7.5	7.5
HDS residuals												
Claus		0.9	0.2		0.6	0.2	2.3	3.0	4.5	0.2	7.5	11.7
Hydrogene Units	0.8	1.3	1.1	0.3	1.0	0.6		3.4	2.1	1.4	5.5	10.4

Unit : million of ton/year

Table 3.5.8 – Cost of investments in refining (2005-2020)

Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8 & Z9	
North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
23.7	22.6	11.6	5.9	15.2	15.4	29.4	68.0	64.0	17.5	131.9	255.8

Unit : G$

3.5.5 CO_2 Emissions

Table 3.5.9 CO_2 Emission of the refineries

zone		Total	Upgraders	Refineries	Detail of the refineries : Processing units	Hydrogene prod.
Z1	North Am.	247.2	67.5	179.7	143.2	36.5
Z2	Latin Am.	79.4	40.1	39.3	34.6	4.7
Z3	North Eur.	56.4	0.0	56.4	43.0	13.5
Z4	South Eur.	27.6	0.0	27.6	21.6	6.0
Z5	CIS	32.2	0.0	32.2	26.8	5.4
Z6	Africa	26.1	0.0	26.1	24.2	1.8
Z7	Midle East	61.0	0.0	61.0	51.1	9.8
Z8	China	67.5	0.0	67.5	55.2	12.3
Z9	Asia & Pac.	133.4	0.0	133.4	103.0	30.3
Total		730.8	107.6	623.2	502.8	120.5

Unit : million of ton

3.5.6 Marginal costs

Table 3.5.10 Marginal cost

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Gasoline	851.2	825.7	789.7	792.5	785.3	786.5	822.9	824.4	846.9
Diesel oil	716.0	762.6	786.0	786.0	731.5	740.2	705.8	739.0	725.3
Jet fuel	783.1	766.4	819.6	765.2	834.8	782.2	853.9	934.1	897.7
HFO 1%	649.8	618.5	602.8	607.9	602.6	632.4	610.2	602.6	611.4

Unit : US$/ton

Table 3.5.11 Ratio Marginal cost/crude oil price

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Gasoline	1.28	1.25	1.19	1.20	1.18	1.19	1.24	1.24	1.28
Diesel oil	1.08	1.15	1.19	1.19	1.10	1.12	1.06	1.11	1.09
Jet fuel	1.18	1.16	1.24	1.15	1.26	1.18	1.29	1.41	1.35
HFO 1%	0.98	0.93	0.91	0.92	0.91	0.95	0.92	0.91	0.92

3.6 Simulation for 2030 – oil product demand : baseline scenario

The results of the simulation which are presented in the following paragraphs are based on the PRIMES baseline scenario. As before, the oil product demand which is considered in the modelling approach is always the final oil product demand and the demand for electricity generation. Note, that the biofuel share of the automotive fuel consumption (gasoline and diesel oil) is deduced from the final demand.

Thus, according to the PRIMES baseline scenario, the oil product demand which is addressed to the refining industry has been derived (table 3.6.1 in TOE and table 3.6.2 in metric tonnes).

Table 3.6.1 – European oil product demand (TOE)

	2005	2010	2015	2020	2025	2030
LPG	27.2	29.0	29.9	29.4	29.2	28.5
Naphtha	46.2	42.9	43.2	42.3	41.9	41.0
Gasoline	115.6	105.0	101.5	98.9	95.0	92.9
Jet Fuel	49.7	52.0	57.9	63.4	65.0	65.5
Oth. Kerosene	6.2	2.3	2.3	2.1	1.9	1.8
Heating oil	106.1	98.8	95.4	89.2	85.1	81.6
Gas oil	182.9	188.5	197.3	196.1	190.9	179.8
Heavy Fuel Oil	49.0	25.6	24.3	20.9	16.4	12.5
Lubricant	5.9	5.6	6.0	6.2	6.3	6.5
Bitimen	19.1	18.1	19.3	20.0	20.3	20.9
Pet. Coke	5.9	5.6	6.0	6.2	6.3	6.5
Mar. Bunker	43.5	42.2	43.6	43.8	44.6	45.6
Total	657.2	615.6	626.7	618.5	602.8	582.9

Unit : million ot TOE

Table 3.6.2 - European oil product demand (metric tons)

	Conv. factor	2005	2010	2015	2020	2025	2030
LPG	1.095	24.8	26.5	27.3	26.9	26.6	26.0
Naphtha	1.048	44.1	41.0	41.3	40.4	40.0	39.1
Gasoline	1.048	110.3	100.2	96.9	94.3	90.6	88.6
Jet Fuel	1.048	47.4	49.6	55.2	60.5	62.1	62.5
Oth. Kerosene	1.048	5.9	2.2	2.2	2.0	1.8	1.7
Heating oil	1	106.1	98.8	95.4	89.2	85.1	81.6
Gas oil	1	182.9	188.5	197.3	196.1	190.9	179.8
Heavy Fuel Oil	0.952	51.4	26.9	25.5	21.9	17.2	13.1
Lubricant	0.952	6.2	5.9	6.3	6.5	6.6	6.8
Bitimen	0.952	20.0	19.0	20.3	21.0	21.4	21.9
Pet. Coke	0.762	7.7	7.3	7.9	8.1	8.3	8.5
Mar. Bunker	0.952	45.7	44.3	45.8	46.0	46.8	47.9
Total		652.6	610.2	621.3	613.0	597.4	577.5

Unit : million of tons

The European oil product demand is decreasing of 12% over the period 2005-2030. The share of the different products have a slow evolution during this period : gasoline stands for around 16% of the total oil product demand whilst the diesel oil share increases from 28% to 31%.

Table 3.6.3 Difference between baseline and reference scenario

	Δ(bsl-ref.)
LPG	1.1
NPH	0.0
GSL	1.2
JET	-1.0
KRS	0.1
HTO	8.0
GDO	6.2
RFO	0.9
LUB	0.0
BTM	0.0
CKP	0.0
MAB	-0.1
Total	16.5

Unit : million of TOE

According to the PRIMES simulations, the reference crude oil price which is considered in the model is the same that in the reference scenario. It raises up to 105.9 $/b in 2030 (Table 3.2.2).

3.6.1 Refineries throughput

The production of the refineries has been, as for the previous simulations, split in light, medium and heavy products (table 3.6.4 and 3.6.5). The refineries production decreases in North America and in Europe whilst it strongly increase in the other regions of the World. The EU-27 production is reduced to around 577 Mtoe in 2030 (cf Table 3.6.8), i.e. 573 Mt. The production of the recent years was 666.2

Mt in 2005 and 652.4 Mt in 2008. Thus, the European production should represents 14% lower than the 2005 production which is the same evolution than the oil product demand.

Table 3.6.4 Production of the refineries (TOE)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	368.0	104.3	126.2	62.2	106.1	87.0	179.7	291.5	372.2
Medium	387.9	134.7	204.7	109.3	131.6	118.1	188.5	309.2	411.3
Heavy	101.8	45.1	63.6	43.5	65.7	28.2	70.4	85.3	163.9
TOTAL	857.7	284.2	394.5	215.1	303.5	233.3	438.7	686.0	947.4

Unit : million of TOE

Table 3.6.5 Production of the refineries (metric tons)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	349.3	98.9	119.8	58.9	100.7	82.3	170.3	277.1	353.4
Medium	382.9	134.0	202.3	108.4	130.0	116.9	186.4	304.3	406.0
Heavy	114.8	49.1	67.5	47.2	69.3	29.8	74.4	91.9	175.2
TOTAL	846.9	282.0	389.7	214.6	300.0	229.0	431.1	673.4	934.6

Unit : million of tons

3.6.2 Crude oil supply

The crude oil supply of the refineries will grow up to 4520 million of tons which is 21% higher than the 2005 supply. However, the API degree (35.0) and the sulphur content (1.49%) simulated for 2030 are close to the 2005 values.

Table 3.6.6 – Crude oil supply of the refineries

		2005			2030		
Area		Quantity	API	Sulphur %	Quantity	API	Sulphur %
Z1	North Am.	1075.6	34.6	1.49	887.7	36.2	1.53
Z2	Latin Am.	215.3	31.2	1.71	300.2	28.7	1.69
Z3	North Eur.	487.3	33.7	1.24	407.7	33.4	1.26
Z4	South Eur.	244.6	32.4	1.51	226.4	32.6	1.34
Z5	CIS	274.8	31.6	2.08	309.9	33.7	1.49
Z6	Africa	140.7	38.6	0.76	244.5	37.2	0.46
Z7	Midle East	280.4	31.1	2.15	454.0	32.5	1.88
Z8	China	266.8	39.4	0.82	704.1	38.1	1.47
Z9	Asia & Pac.	738.6	37.2	1.61	986.3	36.0	1.62
Total		**3724.2**	**34.7**	**1.51**	**4520.7**	**35.0**	**1.49**

Unit: million of ton

3.6.3 Main flows of products and balance of the European Union

The trade flows of oil products point out the needs of gasoline of North America and the needs of diesel oil of Europe (Table 3.6.7). The CIS refineries have enough refining capacities to export some products in western Europe as well as in Asia.

Table 3.6.7 Trade flows of oil products

Light

FROM ↓	TO →	Z1 North Am.	Z2 Latin Am.	Z3 North Eur.	Z4 South Eur.	Z5 CIS	Z6 Africa	Z7 Midle East	Z8 China	Z9 Asia & Pac.
Z1	North Am.									
Z2	Latin Am.									12.4
Z3	North Eur.					5.2				
Z4	South Eur.	8.8								
Z5	CIS								0.2	16.3
Z6	Africa	8.4								
Z7	Midle East								3.6	
Z8	China									
Z9	Asia & Pac.									

Medium

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	North Am.									
Z2	Latin Am.									
Z3	North Eur.									
Z4	South Eur.									
Z5	CIS			33.1	6.9				2.6	2.5
Z6	Africa									
Z7	Midle East						2.4		13.2	
Z8	China									
Z9	Asia & Pac.									

Heavy

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	North Am.									
Z2	Latin Am.	3.3								
Z3	North Eur.					3.5	0.4			
Z4	South Eur.									
Z5	CIS									
Z6	Africa									
Z7	Midle East									
Z8	China									
Z9	Asia & Pac.									

Unit : million of TOE

The simulation of the oil product balance for EU-27 point out that the global production and consumption are equilibrated. However, there are some important flows of diesel oil imports (around 22% of the demand) and the European refineries should export around 18% of its gasoline production (Table 3.6.8). As for the previous simulations, if there is a more important share of diesel oil in the automotive fuel consumption in the next years than it is projected from the Primes simulations there will be more difficulties to supply gas oil from the European refineries and also more imports of medium distillates, considering heating oil demand unchanged. Moreover, some larger quantities of gasoline from the European refineries should find foreign markets (which is not obvious).

Table 3.6.8 – Simulation of the oil product balance of the European Union in 2030

	Production	Imports	Consumption	Exports
LPG	28.5	0.0	28.5	0.0
Naphtha	39.7	1.3	41.0	0.0
Gasoline	113.1	0.0	92.9	20.2
Jet Fuel	67.1	0.0	65.5	1.7
Oth. Kerosene	1.8	0.0	1.8	0.0
Heating oil	83.2	0.0	81.6	1.6
Gas oil	140.3	39.5	179.8	0.0
Heavy Fuel Oil	18.7	0.0	12.5	6.2
Lubricant	6.5	0.0	6.5	0.0
Bitimen	20.9	0.0	20.9	0.0
Pet. Coke	12.1	0.0	6.5	5.7
Mar. Bunker	45.6	0.0	45.6	0.0
Total	577.4	40.8	582.9	35.3

Unit : million of TOE

3.6.4 Refining capacities

The following table (Table 3.6.9) shows the rate of use of the processing units compared to the calibration date (baseline 100 = 2005). Thus the figures which are greater than 100% are investments.

An other point is that no special features have been put on existing capacities in OECD countries like closure of certain refineries as it could be expected due to economic conditions.

Table 3.6.9 – rate of use of the refining units (baseline 100=2005)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe
Topping	82.5%	139.5%	83.7%	92.6%	112.8%	173.8%	161.9%	263.9%	133.5%	86.6%
Cat. Reformer	67.6%	194.1%	64.7%	81.2%	105.5%	132.3%	131.9%	485.1%	134.3%	70.3%
FCC	55.5%	140.5%	85.2%	100.0%	124.6%	556.8%	445.7%	361.0%	200.8%	89.3%
RCC	104.7%	377.5%	100.0%			204.6%	558.5%	208.2%	182.0%	100.0%
CKR	90.0%	315.6%	196.7%	135.8%	77.0%		5071.4%	308.3%	215.0%	153.1%
HDS gas oil	160.3%	357.0%	163.1%	141.9%	114.9%		240.4%	424.6%	217.6%	154.5%
HCK 78%conv.			122.0%	100.0%		0.0%	100.0%		100.0%	117.5%
HCK Full/Naphta/Jet	100.0%									
HDS residuals		43.1%	258.0%	69.0%		100.0%	158.3%	100.0%	118.1%	189.0%

The main investments concern the regional areas Z7 (Middle East), Z8 (China) and Z9 (Other Asia and Pacific) in order to reach the increasing demand (Table 3.6.10).

In Europe and North America, the slowdown of the demand affects the production of the refineries. Consequently, the rates of use of the topping units decrease (in the same proportion than the oil product demand).

Table 3.6.10 – Investments in refining (2005-2030)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8&Z9	
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
Topping unit & VDU		99.6				98.0	90.1	537.7	77.0		614.8	902.5
Reforming Unit & Isom.		21.2	0.6	3.4	8.0	7.2	17.9	82.5	55.0	4.0	137.5	195.8
FCC		16.1			8.1	43.7	58.4	35.2	45.5		80.7	207.0
RCC	0.7	16.4			23.7	2.6	45.4	35.9	45.2		81.1	169.9
Coker (CKR)		30.0	6.0	5.6		4.0	7.0	25.5	24.5	11.5	50.0	102.4
HDS gas oil	211.6	56.5	52.7	40.4	47.1	44.4	79.8	106.6	127.6	93.1	234.2	766.7
HDT vacuum gas oil	11.8	23.3	1.7	1.0	11.5		27.1	44.6	61.7	2.7	106.3	182.7
Hydrocraking (HCK)			5.3					79.3		5.3	79.3	84.6
HDS residuals			6.2				16.0		10.2	6.2	10.2	32.4
Claus		2.3	0.8		1.2	0.4	4.9	6.2	6.3	0.8	12.6	22.1
Hydrogene Units	1.9	2.2	2.1	0.5	1.6	0.6	2.3	10.2	4.0	2.6	14.2	25.4

Unit : million of ton/year

Note that the modelling approach does not take into account the availability of the engineering companies to build the new processing units over the period and the financial constraints of the companies for investments. Relating to the figures in the table 3.6.10, this issue should not be too difficult to cope with (around 50 to 90 refineries in 25 years to be built). Also, it should be more interesting to build them in the growing or emerging markets or in the oil producing countries rather than in the decreasing markets with some consequences on the international trade flows of products.

The following table gives an estimation of the investment costs requirements over the 25 years period 2005-2030. It should reach around 21 billion of dollars in Europe which represents 5.4% of the total investments of the worldwide refining sector.

Table 3.6.11 – Cost of investments in refining (2005-2030)

Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8 & Z9	
North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
26.1	37.9	14.7	6.6	20.3	23.0	55.7	123.7	82.5	21.3	206.1	390.5

Unit : G$

3.6.5 CO_2 Emissions

The CO_2 emissions are split between the emissions of the up graders and those from the refineries, stricto sensu (Table 3.6.12). As for the previous simulations with the PRIMES Reference scenario, the needs of hydrogen in the refineries contribute to increase the CO_2 emissions. The direct emission due to the hydrogen production could stand for around 20% of the refineries emissions in 2030 (14% in 2005) as natural gas steam reforming should be he dominant technology. In addition contribution of the up-grading of extra heavy crude (Canada and Venezuela) will account for more than 13% in 2030 (4% in 2005).

Table 3.6.12 CO_2 Emission of the refineries

zone		Total	Upgraders	Refineries	Detail of the refineries : Processing units	Hydrogene prod.
Z1	North Am.	233.4	67.5	165.9	126.6	39.3
Z2	Latin Am.	90.7	40.1	50.6	43.3	7.3
Z3	North Eur.	67.4	0.0	67.4	51.1	16.3
Z4	South Eur.	34.1	0.0	34.1	27.6	6.5
Z5	CIS	40.1	0.0	40.1	33.1	7.0
Z6	Africa	34.3	0.0	34.3	32.4	1.9
Z7	Midle East	78.5	0.0	78.5	61.6	17.0
Z8	China	110.9	0.0	110.9	79.9	31.0
Z9	Asia & Pac.	145.7	0.0	145.7	110.3	35.5
Total		835.1	107.6	727.6	565.8	161.8

Unit : million of ton

3.6.6 Marginal costs

According to a reference crude oil price of 105.9$/b (i.e. 794.25$/t) , the ratio gasoline/crude oil remains around 1.25 and the ratio diesel oil/crude oil is between 1.1 and 1.15 in most of the regions which means that we could say that they do not change over the period.

However the ratio heavy fuel oil/crude oil grows up to 0.95 which clearly reflects the desulphurization cost of the products.

Table 3.6.13 Marginal cost

	Z1 North Am.	Z2 Latin Am.	Z3 North Eur.	Z4 South Eur.	Z5 CIS	Z6 Africa	Z7 Middle East	Z8 China	Z9 Asia & Pac.
Gasoline	993.4	982.0	968.4	964.0	989.0	925.6	1000.5	1043.0	1025.1
Diesel oil	870.5	901.7	906.6	906.6	823.8	869.7	833.7	792.1	853.4
Jet fuel	922.6	903.1	953.3	900.0	964.0	911.0	983.2	1160.0	1026.9
HFO 1%	765.8	738.5	718.3	742.0	752.9	761.2	728.2	742.3	751.6
Mar. Bunker 0.5%	780.6	749.3	737.0	753.3	770.9	770.8	745.9	759.0	770.2

Unit : US$/ton

3.7 Variant of the 2030 simulation – PRIMES baseline scenario, without new marine bunker fuel specification

The following simulation has been carried out with the PRIMES baseline scenario which is described in paragraph 3.6 and without any change of marine bunker specifications after 2012: 1% sulphur content in the SECA and 3.5% sulphur content in the other areas.

3.7.1 Refineries throughput

Table 3.7.1 Production of the refineries (TOE)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	367.4	94.4	129.3	60.8	112.0	86.3	175.9	295.2	375.2
Medium	387.9	134.7	202.0	100.3	130.6	116.9	192.3	309.2	409.5
Heavy	103.1	43.7	67.6	43.1	69.3	16.6	72.9	87.9	161.3
TOTAL	858.5	272.8	398.9	204.2	311.9	219.7	441.1	692.3	946.0

Unit : million of TOE

Table 3.7.2 Production of the refineries (metric tons)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	348.7	89.4	122.8	57.6	106.5	81.6	166.7	280.5	356.3
Medium	382.9	134.0	199.6	99.5	129.0	115.7	190.0	304.3	404.3
Heavy	116.2	47.7	71.5	46.7	73.0	17.5	76.9	94.7	172.4
TOTAL	847.8	271.1	393.9	203.7	308.4	214.8	433.6	679.6	933.0

Unit : million of tons

3.7.2 Crude oil supply

The crude oil supply of the refineries will grow up to 4501 million of tons which is 20% higher than the 2005 supply. However, the API degree (34.6) and the sulphur content (1.4%) simulated for 2030 are close to the 2005 values.

Table 3.7.3 – Crude oil supply of the refineries

		2005			2030		
Area		Quantity	API	Sulphur %	Quantity	API	Sulphur %
Z1	North Am.	1075.6	34.6	1.49	887.0	36.1	1.51
Z2	Latin Am.	215.3	31.2	1.71	287.5	28.9	1.56
Z3	North Eur.	487.3	33.7	1.24	411.0	33.4	1.29
Z4	South Eur.	244.6	32.4	1.51	215.1	32.3	1.54
Z5	CIS	274.8	31.6	2.08	319.2	35.8	1.52
Z6	Africa	140.7	38.6	0.76	230.5	38.1	0.31
Z7	Midle East	280.4	31.1	2.15	456.1	33.0	1.66
Z8	China	266.8	39.4	0.82	709.9	38.3	1.52
Z9	Asia & Pac.	738.6	37.2	1.61	984.6	35.2	1.72
Total		**3724.2**	**34.7**	**1.51**	**4501.0**	**35.1**	**1.50**

Unit: million of ton

3.7.3 Main flows of products and balance of the European Union

Table 3.7.4 Trade flows of oil products

Light

FROM ↓	TO →	Z1 North Am.	Z2 Latin Am.	Z3 North Eur.	Z4 South Eur.	Z5 CIS	Z6 Africa	Z7 Midle East	Z8 China	Z9 Asia & Pac.
Z1	North Am.									
Z2	Latin Am.	0.6								1.9
Z3	North Eur.	3.2				5.2				
Z4	South Eur.	6.2								
Z5	CIS									24.5
Z6	Africa	7.6								
Z7	Midle East									
Z8	China									
Z9	Asia & Pac.									

Medium

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	North Am.									
Z2	Latin Am.									
Z3	North Eur.									
Z4	South Eur.									
Z5	CIS			26.8	12.9					4.3
Z6	Africa									
Z7	Midle East						3.6		15.7	
Z8	China									
Z9	Asia & Pac.									

Heavy

FROM ↓	TO →	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Z1	North Am.									
Z2	Latin Am.	1.9								
Z3	North Eur.						9.1			
Z4	South Eur.									
Z5	CIS									
Z6	Africa	0.1								
Z7	Midle East						3.0			
Z8	China									2.7
Z9	Asia & Pac.									

Unit : million of TOE

Table 3.7.5 – Simulation of the oil product balance of the European Union in 2030

	Production	Imports	Consumption	Exports
LPG	27.4	0.0	27.4	0.0
Naphtha	40.2	0.8	41.0	0.0
Gasoline	114.5	0.0	91.7	22.9
Jet Fuel	68.1	0.0	66.5	1.7
Oth. Kerosene	1.8	0.0	1.7	0.0
Heating oil	75.6	0.0	73.5	2.0
Gas oil	136.6	37.0	173.6	0.0
Heavy Fuel Oil	22.8	0.0	11.5	11.3
Lubricant	6.5	0.0	6.5	0.0
Bitimen	20.9	0.0	20.9	0.0
Pet. Coke	11.2	0.0	6.5	4.8
Mar. Bunker	45.7	0.0	45.7	0.0
Total	571.3	37.8	566.4	42.7

Unit : million of TOE

3.7.4 Refining capacities

The following table (Table A9.6) shows the rate of use of the processing units compared to the calibration date (baseline 100 = 2005). Thus the figures which are greater than 100% are investments.

An other point is that no special features has been put on existing capacities in OECD countries like closure of certain refineries as it could be expected due to economic conditions.

Table 3.7.6 – rate of use of the refining units (baseline 100=2005)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe
Topping	82.5%	133.5%	84.4%	88.0%	116.2%	163.8%	162.7%	266.0%	133.3%	85.6%
Cat. Reformer	66.2%	162.5%	64.2%	75.6%	104.5%	128.8%	153.9%	494.1%	133.5%	68.1%
FCC	57.4%	139.9%	89.2%	100.0%	100.0%	557.9%	484.0%	404.6%	213.3%	92.2%
RCC	100.0%	205.4%	100.0%			237.2%	468.2%	180.2%	209.7%	100.0%
CKR	90.0%	315.6%	196.7%	135.8%	77.0%		5071.4%	281.5%	230.3%	153.1%
HDS gas oil	160.3%	356.7%	166.8%	127.3%	119.8%		233.4%	418.8%	223.9%	150.8%
HCK 78%conv.			100.0%	100.0%		18.2%	100.0%		100.0%	100.0%
HCK Full/Naphta/Jet	100.0%		#DIV/0!							
HDS residuals		43.1%	100.0%	34.1%		100.0%	100.0%	100.0%	100.0%	75.9%

Table 3.7.7 – Investments in refining (2005-2030)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8&Z9	
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
Topping unit & VDU		97.2				91.2	122.0	550.4	79.2		629.6	940.1
Reforming Unit & Isom.		16.0	0.7	4.4	10.1	6.4	18.8	86.2	51.4	5.1	137.6	194.0
FCC		15.9				43.8	64.8	41.1	51.2		92.3	216.8
RCC		6.2			25.0	3.4	36.4	26.6	60.5		87.1	158.2
Coker (CKR)		30.0	6.0	5.6		4.0	7.0	22.2	27.8	11.5	50.0	102.4
HDS gas oil	210.5	56.4	55.8	32.1	42.3	44.7	76.8	105.1	133.2	87.9	238.3	757.0
HDT vacuum gas oil	0.4	22.8			0.0		11.4	47.5	61.3		108.8	143.4
Hydrocraking (HCK)								78.2			78.2	78.2
HDS residuals												
Claus		1.2	0.0		0.7	0.2	2.9	5.9	5.0	0.0	10.9	15.9
Hydrogene Units	1.3	1.7	1.3	0.2	1.3	0.6		9.4	3.3	1.5	12.7	19.1

Unit : million of ton/year

Table 3.7.8 – Cost of investments in refining (2005-2030)

Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8 & Z9	
North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
23.0	33.1	11.6	5.8	16.9	22.8	47.7	123.3	81.5	17.4	204.8	365.8

Unit : G$

3.7.5 CO_2 Emissions

Table 3.7.9 CO_2 Emission of the refineries

zone		Total	Upgraders	Refineries	Detail of the refineries : Processing units	Hydrogene prod.
Z1	North Am.	230.5	67.5	163.0	125.2	37.7
Z2	Latin Am.	85.6	40.1	45.5	39.6	5.9
Z3	North Eur.	65.3	0.0	65.3	51.2	14.1
Z4	South Eur.	32.4	0.0	32.4	26.8	5.7
Z5	CIS	35.9	0.0	35.9	29.6	6.3
Z6	Africa	34.7	0.0	34.7	32.7	2.0
Z7	Midle East	72.6	0.0	72.6	62.0	10.6
Z8	China	109.0	0.0	109.0	80.3	28.7
Z9	Asia & Pac.	145.4	0.0	145.4	111.9	33.5
Total		811.4	107.6	703.9	559.3	144.5

Unit : million of ton

3.7.6 Marginal costs

Table 3.7.10 Marginal cost

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Gasoline	999.8	983.8	974.6	973.8	989.8	931.6	1001.4	1043.3	1026.9
Diesel oil	865.5	900.6	895.0	895.0	825.1	867.3	831.2	792.2	851.4
Jet fuel	927.6	902.7	969.0	899.7	969.4	908.4	988.6	1159.5	1032.3
HFO 1%	766.5	739.8	720.6	746.0	754.1	759.9	728.7	742.4	752.0

Unit : US$/ton

3.8. Results of the simulation with the PRIMES baseline scenario : intermediate results for 2020

In this paragraph, the intermediate results for 2020 with the PRIMES baseline scenario are presented.

3.8.1 Refineries throughput

Table 3.8.1 Production of the refineries (TOE)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	436.9	79.4	140.5	65.9	95.0	68.5	136.3	208.9	341.6
Medium	378.3	116.2	214.5	109.4	119.1	100.0	156.8	232.1	374.1
Heavy	112.9	52.6	69.9	44.1	62.7	19.7	70.3	75.4	163.1
TOTAL	928.1	248.3	424.9	219.4	276.8	188.2	363.4	516.3	878.8

Unit : million of TOE

Table 3.8.2 Production of the refineries (metric tons)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
Production	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Light	414.4	75.2	133.4	62.4	90.2	64.8	129.2	198.2	324.0
Medium	373.4	115.6	212.2	108.5	117.6	99.0	155.0	229.1	369.3
Heavy	126.5	56.7	74.0	47.8	66.1	20.8	74.1	80.9	174.5
TOTAL	914.3	247.5	419.5	218.7	273.9	184.5	358.3	508.2	867.8

Unit : million of tons

3.8.2 Crude oil supply

Table 3.8.3 – Crude oil supply of the refineries

		2005			2020		
Area		Quantity	API	Sulphur %	Quantity	API	Sulphur %
Z1	North Am.	1075.6	34.6	1.49	950.2	35.9	1.53
Z2	Latin Am.	215.3	31.2	1.71	265.6	29.0	1.61
Z3	North Eur.	487.3	33.7	1.24	438.6	33.7	1.26
Z4	South Eur.	244.6	32.4	1.51	232.2	31.9	1.48
Z5	CIS	274.8	31.6	2.08	283.1	34.2	1.58
Z6	Africa	140.7	38.6	0.76	197.8	37.2	0.34
Z7	Midle East	280.4	31.1	2.15	377.2	31.5	1.77
Z8	China	266.8	39.4	0.82	529.2	36.8	1.37
Z9	Asia & Pac.	738.6	37.2	1.61	907.1	34.5	1.78
Total		**3724.2**	**34.7**	**1.51**	**4181.0**	**34.4**	**1.51**

Unit: million of ton

3.8.3 Main flows of products and balance of the European Union

Table 3.8.4 Trade flows of oil products

Light

		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
FROM ↓	**TO →**	**North Am.**	**Latin Am.**	**North Eur.**	**South Eur.**	**CIS**	**Africa**	**Midle East**	**China**	**Asia & Pac.**
Z1	**North Am.**									
Z2	**Latin Am.**	2.2								
Z3	**North Eur.**	5.9				5.2				
Z4	**South Eur.**	9.8								
Z5	**CIS**								11.8	11.9
Z6	**Africa**	4.6								
Z7	**Midle East**									
Z8	**China**									
Z9	**Asia & Pac.**									

Medium

FROM ↓	**TO →**	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**
Z1	**North Am.**									
Z2	**Latin Am.**									
Z3	**North Eur.**									
Z4	**South Eur.**									
Z5	**CIS**			30.9	5.6				5.4	3.4
Z6	**Africa**									
Z7	**Midle East**				3.4				10.3	
Z8	**China**									
Z9	**Asia & Pac.**									

Heavy

FROM ↓	**TO →**	**Z1**	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**	**Z9**
Z1	**North Am.**									
Z2	**Latin Am.**	13.0								
Z3	**North Eur.**						9.2			
Z4	**South Eur.**									
Z5	**CIS**									
Z6	**Africa**									
Z7	**Midle East**									
Z8	**China**									
Z9	**Asia & Pac.**									

Unit : million of TOE

Table 3.8.5 – Simulation of the oil product balance of the European Union in 2020

	Production	Imports	Consumption	Exports
LPG	29.3	0.0	29.3	0.0
Naphtha	41.4	1.0	42.3	0.0
Gasoline	123.4	0.0	96.4	27.0
Jet Fuel	65.2	0.0	63.6	1.6
Oth. Kerosene	2.1	0.0	2.1	0.0
Heating oil	85.6	0.0	84.3	1.3
Gas oil	149.0	39.3	188.3	0.0
Heavy Fuel Oil	27.5	0.0	16.1	11.5
Lubricant	6.2	0.0	6.2	0.0
Bitimen	20.0	0.0	20.0	0.0
Pet. Coke	10.7	0.0	6.2	4.6
Mar. Bunker	44.0	0.0	44.0	0.0
Total	604.5	40.2	598.8	45.9

Unit : million of TOE

3.8.4 Refining capacities

Table 3.8.6 – rate of use of the refining units (baseline 100=2005)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe
Topping	88.3%	123.4%	90.0%	95.0%	103.0%	140.6%	134.5%	198.3%	122.8%	91.7%
Cat. Reformer	95.4%	135.7%	76.2%	86.8%	100.0%	102.9%	128.2%	342.8%	123.4%	79.8%
FCC	59.4%	113.3%	87.2%	100.0%	100.0%	443.6%	381.1%	383.8%	197.7%	90.7%
RCC	100.0%	100.0%	100.0%			100.2%	368.3%	145.7%	154.2%	100.0%
CKR	90.0%	315.6%	196.7%	130.3%	83.2%		5071.4%	251.1%	247.9%	149.1%
HDS gas oil	152.4%	325.7%	172.5%	142.3%	106.6%		195.7%	353.2%	209.8%	160.3%
HCK 78%conv.			100.0%	100.0%		0.0%	100.0%		100.0%	100.0%
HCK Full/Naphta/Jet	100.0%									
HDS residuals		43.1%	100.0%	34.1%		92.8%	100.0%	100.0%	100.0%	75.9%

Table 3.8.7 – Investments in refining (2005-2030)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8&Z9	
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
Topping unit & VDU		69.5				44.9	18.1	273.6	0.9		274.5	406.9
Reforming Unit & Isom.	8.5	11.2	2.4	2.2	9.2	0.9	9.8	49.6	42.7	4.7	92.3	136.6
FCC		5.3				32.9	47.5	38.2	44.1		82.4	168.0
RCC					21.7	0.0	26.6	15.2	29.9		45.0	93.3
Coker (CKR)		30.0	6.0	4.7		4.0	7.0	18.5	31.5	10.7	50.0	101.6
HDS gas oil	197.6	49.6	60.5	40.7	37.3	38.9	60.8	88.7	120.7	101.2	209.4	694.8
HDT vacuum gas oil	0.6	6.5			0.0		9.9	48.7	54.0		102.7	119.8
Hydrocraking (HCK)								7.5			7.5	7.5
HDS residuals												
Claus		0.9	0.2		0.6	0.2	2.3	3.0	4.5	0.2	7.5	11.7
Hydrogene Units	0.8	1.3	1.1	0.3	1.0	0.6		3.4	2.1	1.4	5.5	10.4

Unit : million of ton/year

Table 3.8.8 – Cost of investments in refining (2005-2020)

Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z3 & Z4	Z8 & Z9	
North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Midle East	China	Asia & Pac.	Europe	Asia	Total
23.7	22.6	11.6	5.9	15.2	15.4	29.4	68.0	64.0	17.5	131.9	255.8

Unit : G$

3.8.5 CO_2 Emissions

Table 3.8.9 CO_2 Emission of the refineries

zone		Total	Upgraders	Refineries	Detail of the refineries : Processing units	Hydrogene prod.
Z1	North Am.	247.2	67.5	179.7	143.2	36.5
Z2	Latin Am.	79.4	40.1	39.3	34.6	4.7
Z3	North Eur.	56.4	0.0	56.4	43.0	13.5
Z4	South Eur.	27.6	0.0	27.6	21.6	6.0
Z5	CIS	32.2	0.0	32.2	26.8	5.4
Z6	Africa	26.1	0.0	26.1	24.2	1.8
Z7	Midle East	61.0	0.0	61.0	51.1	9.8
Z8	China	67.5	0.0	67.5	55.2	12.3
Z9	Asia & Pac.	133.4	0.0	133.4	103.0	30.3
Total		730.8	107.6	623.2	502.8	120.5

Unit : million of ton

3.8.6 Marginal costs

Table 3.8.10 Marginal cost

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Gasoline	851.2	825.7	789.7	792.5	785.3	786.5	822.9	824.4	846.9
Diesel oil	716.0	762.6	786.0	786.0	731.5	740.2	705.8	739.0	725.3
Jet fuel	783.1	766.4	819.6	765.2	834.8	782.2	853.9	934.1	897.7
HFO 1%	649.8	618.5	602.8	607.9	602.6	632.4	610.2	602.6	611.4

Unit : US$/ton

Table 3.8.11 Ratio Marginal cost/crude oil price

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9
	North Am.	Latin Am.	North Eur.	South Eur.	CIS	Africa	Middle East	China	Asia & Pac.
Gasoline	1.28	1.25	1.19	1.20	1.18	1.19	1.24	1.24	1.28
Diesel oil	1.08	1.15	1.19	1.19	1.10	1.12	1.06	1.11	1.09
Jet fuel	1.18	1.16	1.24	1.15	1.26	1.18	1.29	1.41	1.35
HFO 1%	0.98	0.93	0.91	0.92	0.91	0.95	0.92	0.91	0.92

3.9 Sensitivity analysis of the OURSE model simulations

The sensitivity analysis has been done from the OURSE projection for 2030 related to the PRIMES reference scenario. As the potential IMO impacts on the European refining tool could be dramatically related to the crude oil supply assessments, the new simulation has been focused on this specific item.

Basically the OURSE model is an aggregated refining model which takes into account nine crude oil categories for 2030 projections - Ultra Light Sweet Crude oil, Sweet Light Crude Oil, Sour Light Crude oil, Sweet Medium Crude Oil, Medium Sour Medium rude Oil, Sour Medium Crude Oil, Sweet Heavy Crude Oil, Sour Heavy Crude Oil and Bitumen and Extra-Heavy Oil. These nine categories are summarized through five typical crude oil (Brent, Arabian Light, Arabian Heavy, Forcados, Condensate). The "Forcados" crude oil availability role for the European supply, due to its yield in medium (55.8%) and heavy (31.4%) distillates as well as low sulphur content of residuals (0.3%), will be key for refinery adaptation.

In the reference simulation run, the European refineries aim to be supply by a large amount of such crude oil to produce the increasing share of medium distillate of the European consumption. Consequently, in the sensitivity analysis, the "Forcados" typical crude oil share in the total European supply is limited to the observed share in 2005 which stands to around 14% (table 3.9-2).

Table 3.9.2 European crude oil supply in 2030

2030 CASE	Supply			Brent	Arabian Light	Arabian Heavy	Forcados	Condensates	LR resid Arabian light
	Mt	°API	%m S	%m	%m	%m	%m	%m	%m
Ref with IMO	614	33,2	1,30	9,6	26,3	24,8	31,5	4,7	3,1
New without IMO	610	33,2	1,57	18,0	38,0	27,0	13,0	2,0	2,0
New with IMO	611	33,3	1,68	10,0	41,0	29,7	12,5	4,2	2,6

The following tables summarized the results of the new simulation for 2030 with the PRIMES reference scenario with and without implementation of the IMO specifications.

From this sensitivity analysis, we could clearly noticed that the implementation of the IMO marine bunker fuel specifications should increase respectively the CO_2 emission of 5.6 Mt (Table 3.9.4) and the total European refineries investments of US$10 billions (Table 3.9.3) The reduction from the process unit is due to FCC activity decrease.

Table 3.9.3 Investment costs in refining (2005-2030) hydrogen excluded

	Total	HCK	Mild HCK	Coker	ARDS	VRDS	
	US G$	Mt	Mt	Mt	Mt	Mt	
New without IMO	22	27,1		11,5	-	4,3	
New with IMO	32	30,5	9,8	11,5	8,7	18,8	
Delta due to IMO	**10**	**3,4**	**9,8**	**0**	**8,7**	**14,5**	
(*) investments relative to optimal feedstocks of process units in the LP simulation for 2005 year (reference).							

Table 3.9.4 CO2 emissions

unit : Mt	total	Process unit	Hydrogen
New without IMO	104,7	78,0	26,7
New with IMO	110,3	77,5	32,8
Delta due to IMO	**5,6**	**-0,5**	**6,1**

Conclusion

The OURSE model is a worldwide aggregated refining model which is designed to simulate the oil product supply for the POLES model. The model is based on a linear programming (LP) model. Such model is frequently used in the refining industry, both for refinery management and for investment analysis. Furthermore, marginal cost pricing is relevant for the oil products.

Because the model designed to represent the world-wide refining industry must have a limited number of equations, a representative refinery has been defined for nine main regions in the world - North and Central America, Latin America, North and South Europe, CIS, Africa, Middle East, China, Other Asia and Oceania.

The results of the calibration run in 2005 have been compared to the observed figures: these show a 5% percentage error for the refining throughput, and a 15% percentage error for the marginal costs of the products (Lantz & Bertout, 2008).

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In the new version of the model, more processing units have been introduced the refining scheme, a larger set of crude oil qualities is considered, all the figures concerning the CO_2 emissions from the refining processes and from the refineries fuel have been revised. All these improvements have been done to provide a modelling tool which could be useful to assess the consequences of different scenarios on the supply side and/or on the demand side.

A prospective exercise for the oil refining industry has been carried out with the worldwide refining model OURSE according to the oil product demand projections of the European Commission for Europe (and the IFP projections for the rest of the World).

Thus, we consider a 14% decrease of the European oil product demand from 2005 to 2030 which will decrease to 566 Mtoe in 2030. During the same period, the worldwide oil product demand will have a 23% raise up to 4411 Mtoe in 2030. The share of light, medium and heavy oil products will be modified with a decreasing share of heavy products and a more important consumption of medium distillates. Nevertheless, in the Primes European projections, the respective share of gasoline and diesel oil in the automotive fuel consumption is not strongly affected during the next two decades.

However, the specification of the products will be more severe, especially for the marine bunkers (future IMO specifications).

On the supply side, the crude oil supply has been estimated until 2030. This analysis is based on IFP geosciences expertises. In 2030, the API degree of the conventional crude oil will slowly decrease. However, this will be balanced by the increasing share of condensates in the refinery supply and the availability of upgraded crude oil from the extra-heavy oil. Finally, the API degree of the refineries supply should remain quite unchanged.

In this context, the main results of the simulation are the following:

The refineries production decreases in North America and in Europe whilst it strongly increases in the other regions of the World. The EU-27 production reduces to around 559 Mtoe in 2030, i.e. 555 Mt. The production of the recent years was 666.2 Mt in 2005 and 652.4 Mt in 2008. Thus, the European production should be 16% lower than the 2005 production which is the same evolution than the oil product demand.

The trade flows of oil products point out the needs of gasoline of North America and the needs of diesel oil of Europe. The simulation of the oil product balance for EU-27 point out that the global production and consumption are equilibrated. However, there are some important flows of diesel oil imports (around 21% of the demand) and the European refineries should export around 18% of its gasoline production.

The main investments concern the Middle East and Asia in order to reach the increasing demand. In Europe and North America, the slowdown of the demand affects the rate of use of the refining units. However, in Europe, some investments in essentially gasoil hydrodesulphurization units and at a lower level VGO/residue hydrodesulphurization (for bunkers quality) and hydrocracking units (as diesel/diesel+gasoline ratio continue to increase slightly) are required.

The needs for hydrogen in the refineries contribute to an increase of the CO_2 emissions. The direct emission due to the hydrogen production could stand for around 20% of the refineries emissions in 2030 (14% in 2005) as natural gas steam reforming should be he dominant technology. In addition contribution of the up-grading of extra heavy crude (Canada and Venezuela) will account for more than 13% of emission in 2030 (4% in 2005).

The analysis of the marginal costs point out that the ratio gasoline marginal cost/crude oil price remains around 1.25 and the ratio diesel oil marginal cost/crude oil price is between 1.1 and 1.15 in most of the regions of the World.

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Annex 1 – Refining units

Table A1.1 Refining units nomenclature

DI	ATMOSPHERIC DISTILLATION
VD	VACUUM DISTILLATION UNIT
D3	DESASPHALTING UNIT C3
D5	DESASPHALTING UNIT C5
HT	DAO HDT
HW	HYDROCONVERSION DES RESIDUS
HO	H-Oil
RF	CATALYTIC REFORMER
RR	REGENERATIVE REFORMER
DR	REFORMATE SPLITTER
PE	FCC FEED HDT (VACUUM GO)
MK	MILD HCK
FC	CATALYTIC CRACKING
CC	CATALYTIC CRACKING
HR	RCC FEED HDT (LONG RUN RESIDUE)
RC	HDT LONG RUN RESID CATALYTIC CRACKING
CR	LONG RUN RESID CATALYTIC CRACKING
HC	HYDROCRACKING FULL
HM	HYDROCRACKING JET
HN	HYDROCRACKING NAPHTA
HK	HYDROCRACKING 78 CONV
DP	DEISOPENTANISEUR
IS	ISOMERIZATION ONCE THROUGH
IR	ISOMERIZATION WITH RECY
AK	ALKYLATION HF
DL	DIMERSOL
TA	TAME UNIT ON LG FROM FCC & RCC
BX	MTBE UNIT
EE	ETBE TOTAL UNIT
VB	VISBREAKING (VACUUM RESIDUE)
CK	COKING delayed
HB	HDS VGO CK
HD	HDS 90 20bar
HX	HDS 97-98 30bar
HA	REVAMP HX 50bar
HJ	DEEP HYDRODESULFURIZATION 75 bar
HH	SELECTIVE HDT OF HEAVY CRACKED NAPHTHA -20 ppm
HI	SELECTIVE HDT OF HEAVY CRACKED NAPHTHA -10 ppm
HL	REF FEED HDT
PS	PSA UNIT
HU	STEAM REFORMER
OX	PARTIAL OX (VACUUM RESIDUE and ASPHALTS)
CG	NG COGENERATION
CY	NGCC
IG	IGCC
CX	CLAUS SANS TGT
CL	MDEA+CLAUS+hydrosulfreen (SRI)

Table A1.2 Refining capacities (reference period 2005-2010)

Processing Unit	Z1 North America	Z2 Latin America	Z3 North-West Europe	Z4 South America	Z5 CIS	Z6 Africa	Z7 Middle East	Z8 China	Z9 Other Asia & Ocenia
DI	1099.00	212.17	564.60	275.15	414.89	164.65	360.57	295.33	842.45
VD	499.08	67.92	238.38	97.82	144.08	27.98	98.82	26.70	203.06
D3	23.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HW	0.00	1.90	0.00	1.49	0.00	0.13	10.15	0.00	1.25
HO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RF	124.97	7.52	20.06	15.22	0.00	18.18	1.21	0.18	0.00
RR	53.24	7.21	34.16	13.02	14.50	2.75	23.32	11.85	56.52
DR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PE	97.24	0.43	25.19	1.60	18.67	0.00	0.00	0.00	8.91
MK	0.00	0.00	11.13	11.74	1.50	0.00	2.67	3.15	8.06
FC	79.82	0.35	28.38	9.39	16.35	0.00	1.85	2.18	12.90
CC	192.45	39.42	51.36	20.90	16.60	9.57	15.04	11.30	32.28
HR	0.00	1.44	3.93	0.77	0.00	1.68	17.24	7.17	55.15
RC	0.00	1.01	2.75	0.00	0.00	1.17	4.95	0.00	38.60
CR	14.36	4.89	7.98	0.00	0.00	1.33	4.95	33.17	16.54
HC	68.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC	68.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HK	0.00	0.00	23.93	6.07	0.00	2.25	0.15	0.00	24.05
HN	68.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HM	68.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DP	2.52	0.46	8.42	4.45	0.00	0.00	0.00	0.00	0.24
IS	42.44	4.42	14.67	5.01	2.47	3.15	7.40	0.00	9.84
IR	0.00	0.00	0.00	0.53	11.43	0.00	1.65	19.27	21.72
AK	9.67	0.00	2.28	0.00	0.00	0.00	0.00	0.15	0.00
DL	6.24	0.00	0.97	1.13	0.00	0.00	0.00	0.00	0.00
TA	0.00	0.00	0.18	0.04	0.00	0.00	0.00	0.00	0.00
BX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	4.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VB	0.00	9.35	45.48	11.61	21.55	5.95	21.84	0.00	22.62
CK	125.81	13.91	6.15	15.57	4.12	0.00	0.14	12.24	21.29
HB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HD	39.32	21.98	16.50	2.29	55.14	0.00	22.34	0.00	62.69
HX	112.53	0.00	0.00	16.58	0.00	0.00	20.14	25.10	23.59
HA	10.66	0.00	67.00	38.09	10.81	0.00	0.00	0.00	2.16
XA	123.19	0.00	67.00	54.67	10.81	0.00	20.14	25.10	25.74
HJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HH	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HL	11.56	0.77	0.64	1.40	0.40	0.00	0.01	1.11	1.92
PS	4.35	0.43	1.60	0.76	0.48	0.54	0.79	0.39	1.81
HU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CX	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CL	12.03	1.44	3.35	2.00	1.89	0.16	2.20	1.69	6.16

Unit : Mt/year

Annex 2 – Nomenclature of the oil products

Table A2.1 Nomenclature of the oil products in the refining model

```
PT    PROPANE TOTAL
BU    BUTANE TOTAL
NA    NAPHTHA
RG    REGULAR 1
RQ    REGULAR 2
ES    PREMIUM 1
EQ    PREMIUM 2
PR    PREMIUM 3
JF    JET FUEL
DO    DIESEL OIL 1
DQ    DIESEL OIL 2
DV    DIESEL OIL 3
DU    DIESEL OIL 4
HO    HEATING OIL 1
HQ    HEATING OIL 2
LF    HEAVY FUEL OIL LS 1% sulfur
HF    HEAVY FUEL OIL HS 3.5% sulfur
MF    MARINE BUNKER ULTRA LS 0.1% Sulphur
BT    BITUMEN MEDIUM
ST    MARINE BUNKER 0.5% Sulphur
LU    LUBRICANTS
FB    REFINERY LIQ. FUEL
KC    PETROLEUM COKE
FS    FEEDSTOCK
```

Table A2.2 - Shares of gasoline grades according to the regional areas

		RG	RQ	ES	EQ	PR
North & Central	America	70%	30%	0%	0%	0%
South	America	0%	0%	100%	0%	0%
North	Europe	0%	0%	0%	0%	100%
South	Europe	0%	0%	0%	0%	100%
CIS		0%	0%	80%	20%	0%
Africa		0%	0%	100%	0%	0%
Middle	East	0%	0%	0%	100%	0%
China		0%	0%	60%	40%	0%
Other Asia &	Oceania	0%	0%	0%	100%	0%

Table A2.3 - Shares of diesel oil qualities according to the regional areas

		DO	DQ	DV	DU
North & Central	America	100%	0%	0%	0%
South	America	0%	100%	0%	0%
North	Europe	0%	0%	100%	0%
South	Europe	0%	0%	100%	0%
CIS		0%	100%	0%	0%
Africa		0%	0%	0%	100%
Middle	East	0%	0%	0%	100%
China		0%	0%	0%	100%
Other Asia &	Oceania	60%	20%	0%	20%

Annex 3 POLES countries and OURSE regions

Region Z1 NorthAmerica , – North and central America:

Canada, United States ,Mexico ,Bahamas, Belize ,Bermuda, Barbados, Costa Rica , Cuba, Dominica, Dominican Rep., Grenada, Guatemala, Honduras Haiti, Netherlands Antilles & Aruba, Jamaica, St. Lucia, Nicaragua, Panama, El Salvador

Region Z2 SouthAmerica :

Trinidad, St Vincent & the Grenadines, Brazil, Argentina, Bolivia Chile, Colombia, Ecuador, Suriname, Guyana, Peru, Paraguay, Uruguay, Venezuela

Region Z3 – North Europe, North and West Europe:

France, United Kingdom, Germany, Austria, Belgium, Luxembourg, Denmark, Finland, Ireland, Netherlands, Sweden, Hungary, Poland, Czech Republic, Slovak Republic, Estonia, Latvia, Lithuania, Slovenia, Bulgaria, Romania, Iceland, Norway, Switzerland

Region Z4 – South Europe :

Italy, Spain, Greece, Portugal, Malta, Cyprus, Turkey, Croatia, Bosnia-Herzegovina, Macedonia, Serbia & Montenegro, Albania

Region Z5 – Russia:

Russia, Ukraine, Armenia, Azerbaijan, Belarus, Geogie, Kazakstan, Kyrgyz Rep., Moldova, Tajikistan, Turkmenistan, Uzbekistan

Region Z6 – Africa:

Egypt, Algeria, Libya, Tunisia, Morocco, Western Sahara, South Africa, Angola, Burundi, Benin, Burkina Faso, Botswana, Central African Rep, Cote d'ivoire, Cameroon, Congo, Comoros, Cape Verde, Djibouti, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Gambia, Guinea-Bissau, Guinea Equatorial, Kenya, Liberia, Lesotho, Madagascar, Mali, Mozambique, Mauritania, Mauritius, Malawi, Namibia, Niger, Nigeria, Rwanda, Sudan, Senegal, Sierra Leone, Somalia, Sao Tome & Principe, Swaziland, Seychelles, Chad, Togo, Tanzania, Uganda, Zimbabwe, Zambia, Zaire,

Region Z7 – MiddleEast:

Israel, Jordan, Lebanon, Syria, United Arab Emirates, Bahrain,
Iran, Iraq, Kuwait,
Oman, Qatar, Saudi Arabia, Yemen

Region Z8 – China:

China

Region Z9 – OtherAsia Other Asia and Pacific:

China, Japan, Australia, Fidji, Kiribati, Vanuatu, New Zealand, Papua New Guinea, Solomon Islands, Tonga, Western Samoa , India, Pakistan, Afghanistan, Bangladesh, Bhutan, Sri-lanka, Maldives, Nepal, South Korea, Indonesia, Brunei, Myanmar (ex Burma), Cambodia, Lao, Macau, Malaysia, Mongolia, Philippines, North Korea, Singapore, Thailand, Taiwan, Vietnam

Annex 4 Computational elements

OURSE has been written with the Gams language. It is linked with the POLES model, handled by Vensim, through a C++ routine which manages the data exchanges between the two models. However, OURSE can be run in stand-mode.

The actual version of the OURSE model contains around 22 000 constraints and 110 000 variables. An interior point method is used for the optimization in stand alone mode (with the Cplex optimization code).

There is an high modularity of the OURSE model for which more than 9 main regions could be considered (for instance North America could split between east and west coast). Furthermore, a largest set of typical crude oil could be introduced in the model. However, this requires the estimation of the model parameters for these feedstocks.

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Abstract

The development of a model of the World Refining for the POLES model (Contract n°151559-2009 A08 FR – with the Joint Research Centre Institute for Prospective Technological Studies of Commission of the European Union) aims to represent the oil product's supply at a world-wide level in a global energy model.
The World oil refining industry faces to several challenges such as the increasing oil derivatives demand in the transport sector, the improvement of the specifications of these products, the crude oil availability and the limitation of carbon emissions. An aggregated refining model linked to the POLES energy model has been developed to study these questions.
The OURSE (Oil is Used in Refineries to Supply Energy) model is a world-wide aggregated refining model which is designed to simulate the world oil product supply for the POLES (Prospective Outlook for the Long-term Energy System) model. OURSE is able to simulate the impact on the world refining industry of changes in the crude oil supply (in costs and qualities) as well as in the oil product demand (in terms of level, structure and specifications).
OURSE also enables to assess the consequences of a carbon emission regulation (caps and taxes) as the adoption of various kinds of alternative fuel policies. More precisely, these impacts are evaluated as regards the world refining structure (investments), but also its balance (production and trade of petroleum products), its pollutant emissions (CO2 and SO2) and its costs (of production, investments, etc.).
Simulations for 2030 were performed. Thus, the paper presents the results of a prospective exercise for the oil refining industry which has been carried out with the worldwide refining model OURSE according to the oil product demand projections of European Commission for Europe with the PRIMES model (European Commission, 2010) and the IFP projections for the rest of the World.

The mission of the Joint Research Centre is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of European Union policies. As a service of the European Commission, the Joint Research Centre functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

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