effect of product quality changes on energy consumption and CO_2 emissions from european refineries

Prepared for the CONCAWE Air Quality Management Group, based on work carried out by the Special Task Force on energy consumption/CO_2 emissions in refineries (AQ/STF-42).

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ABSTRACT

This report quantifies the impact of demand and product quality changes on refinery energy consumption, and therefore CO_2 emissions, covering the period from 1980 through to 2010.

Refinery energy consumption remained relatively constant during the period 1980 to 1990 as investment in conservation measures compensated for increases due to additional processing for product quality and demand changes. This situation will not be mirrored in the period 1990 to 2010. Refinery specific energy consumption is forecast to grow by 50% to 75% by the year 2010, from 5.8% to between 8.7% and 10.2% of refinery intake, to meet future product quality and demand changes with limited economic opportunities for further energy conservation.

Absolute CO_2 emissions are very dependent on the product demand projections and therefore refinery intake. In the two scenarios evaluated, CO_2 emissions by the year 2010 are forecast to range from 98 Mt/yr to 156 Mt/yr , an increase of between 4% and 65% on 1990 levels.

KEYWORDS

CO_2 emission, energy consumption, oil refinery.

CONTENTS

SUMMARY

This report quantifies the impact of demand and product quality changes on refinery energy consumption, and therefore CO_2 emissions, covering the period from 1980 through to 2010.

For the period 1980 to 1990, energy consumption in European refineries remained relatively constant as implementation of energy conservation projects compensated for the energy consumption increase attributable to additional processing for product quality and demand changes. Without the energy conservation measures, specific energy consumption would have increased by about 25%.

Two different demand scenarios developed by A.D. Little for the EU have been used to derive future refinery energy consumption data through to the year 2010, namely:

- "Fuel Oil Decline" (FD) in which the percentage of total fuel oil falls by a third, from 18% to 12% of refinery intake.
- "Sustained Growth" (SG) in which the percentage of total fuel oil is constant at 18% of intake.

In the A.D. Little study, the key environmentally driven product quality changes reflected for future years include:

- Further penetration of unleaded gasoline with reduction in benzene and aromatics levels post year 2000.
- Further reduction in distillate sulphur content and any change in cetane quality as a consequence of increased thermal/cat conversion capacity.
- Reduction in sulphur content in inland/bunker fuels.

In the FD scenario the refinery specific energy consumption is shown to increase some 75% from 1990 to 2010 to meet product quality and demand changes. This is an increase in energy consumption from 5.8% to 10.2%, expressed as a percentage of refinery intake.

For the SG case, the predicted growth over the same period is lower at 50% with an increase in energy consumption from 5.8% to 8.7%.

Refinery energy intensity indices, EII, based on 1990 operations, show a range of 60-160 with a weighted average of 88. Investment cost data per additional tonne fuel saved increases exponentially with improving energy efficiency. The fact that the average EII is coincident with the economic breakeven point supports the view that most of the economically feasible conservation projects were carried out in the 1980s.

In contrast, therefore, to the situation seen in the 1980s, predicted growth in energy consumption in the 1990s to meet perceived environmental needs will not be compensated by significant further energy conservation.

CO_2 emissions are forecast to increase by 75% by year 2010 relative to 1990 in the FD scenario. In the SG scenario, although refinery fuel consumption increases by 50% by year 2010, CO_2 emissions will be 13% greater than 1990 levels as refinery throughput is assumed to reduce by 25% because of lower product demand.

The study concludes that any move to "greener" products, as a result of environmentally driven product quality legislation will increase refinery fuel consumption and therefore CO_2 emissions. These increases and their possible contribution to the greenhouse effect need to form part of any deliberations on future product quality changes.

1. INTRODUCTION

The past decade has seen a major " lightening of the demand barrel" and this change is forecast to continue with particularly strong growth in transportation fuels. At the same time there has been a move to "greener" products as a result of EU requirements for product quality specification changes and this trend is seen to continue. Both of these factors result in an increase in refinery fuel consumption and therefore increases in refinery emissions of CO_2, the gas which would make the largest contribution to any potential enhanced greenhouse effect.

In seeking sustainable development consistent with optimum use of limited resources, it is fundamental in the appraisal of future product quality specification proposals that the total impact on the environment is assessed, since any reduction in product emissions from improved product quality, will be offset to some extent, by a corresponding increase in refinery CO_2 emissions.
The study aims to quantify the impact of demand and product quality changes on refinery energy consumption, and therefore CO_2 emissions, both historically and looking forward to the year 2010.

2. SCOPE

The key aims of the study were to make an overall assessment of the energy requirements to meet forecast changes in the demand barrel and additional energy consumed as a result of more severe processing to meet EU requirements for changes in product quality for refineries in Western Europe. The study has been carried out in two main steps:

a) An historical review of energy consumption in the European petroleum industry covering the period 1980 to 1990.

b) An outlook for the future covering the next two decades.

The data used have all been taken from existing sources including detailed CONCAWE studies.

Energy used in refineries is largely in the form of combustion of fuel where the heat is used for heating process streams directly or in the form of steam and/or electricity. For the purposes of this study any energy imported over the refinery fence in the form of steam or electricity has been ignored, however, any combustion of fuels within the refinery fence to supply heat, steam or electricity to third parties is included. The combined effect of these on the overall balances is likely to be very small.

3. METHODOLOGY

The report has been developed using the following methodology:

- An analysis of statistical energy consumption data for the period 1980 to 1990.
- An assessment of demand and product quality driven changes over this historical period as related to energy consumption.
- An assessment of future additional energy requirements based on product demand and quality forecasts.

3.1. STUDY BASIS AND DATA SOURCES

1. Fuel consumption and crude oil throughput data for the period 1980 - 1990 have been taken from the respective OECD/IEA statistics. [1,2]

2. Product demand and quality assumptions for the period 1990 to 2010 have been based on the scenarios developed by A.D. Little [4] for the EU. They reflect possible developments of the oil market and are defined as "Fuel Oil Decline" (FD), in which the percentage of fuel oil falls by one third, and "Sustained Growth" (SG), in which the percentage of fuel oil is constant. The A.D. Little demand data covered the EU 12 countries. The demand has been adjusted to reflect OECD Europe (including Turkey) using 1989 actuals.

3. Industry data for oil refinery operations and energy efficiency have been derived from a series of regular multiclient studies [3] among a number of CONCAWE members.

4. Factors used to calculate total and specific heat figures together with the corresponding CO_2 emissions have been taken from the OECD/IEA "Oil and Gas Information 1989-1991" [5] and a DGMK study, [10] respectively.

3.2. ENVIRONMENTAL PRODUCT QUALITY ASSUMPTIONS

The EU requirements for product quality changes included in the study were:

For the period 1980 to1990:

- reduction of lead levels in gasoline and introduction of unleaded gasoline,
- reduction of sulphur content in middle distillate.

For the future 1990 to 2010 scenarios from A.D. Little study:

- further penetration of unleaded gasoline and post year 2000, a reduction in gasoline benzene and aromatics levels,
- further reduction in sulphur content and change in cetane quality of the middle distillate pool as a consequence of increased conversion capacity,
- reduction in sulphur content in inland/bunker fuels.

Details of the specific product quality assumptions are shown in the table below.

Table: Specific product quality assumptions (from A.D. Little study)

			"FD Scenario"		"SG Scenario"	
	1980	1990	2000	2010	2000	2010
Gasoline Pool						
RON (Clear)	91.9	93.4	95.0	95.6	95.0	95.6
Ave Lead g/l	0.37	0.17	0.02	Nil	0.02	Nil
Benzene % v max	-	5.0	3.0	1.0	3.0	1.0
Aromatics % v max	-	-	-	30	-	30
Distillate						
Sulphur % w						
Gasoil			0.1	0.1	0.1	0.05
Diesel			0.05	0.05	0.05	0.05
Pool Sulphur % w	0.41	0.23	0.07	0.07	0.07	0.05
Cetane versus 1990 base	-	Base	+ 2[a]	+ 3.5[a]	no change	no change
Fuel Oil						
Demand % split						
RSFO/BFO (2.75% w S)	83%	75%	50%	39%[b]	25%	-
LSFO (0.9% w S)	17%	25%	50%	61%	75%	100%
Fuel Pool % w S	2.44	2.29	1.83	1.61	1.36	0.9

RSFO Regular Sulphur Fuel Oil
BFO Bunker Fuel Oil
LSFO Low Sulphur Fuel Oil

a) For cetane basis see **Section 3.3.**
b) Regular Sulphur Fuel Oil/Bunker Fuel Oil/Low Sulphur Fuel Oil
b) BFO only

3.3. INCREASE IN CONVERSION CAPACITY

The increase in conversion capacity is a direct result of the reduction in demand for the heavy end of the barrel caused by inter-fuel competition (coal, oil, gas and nuclear). This competition is itself a result of changes in technology, especially in the power generation sector, international trade changes, national energy programmes and environmental restrictions on combustion plants. To date, EU requirements for product quality changes have had a relatively small impact on conversion capacity needs.

It is beyond the scope of this study to make a detailed forecast of future conversion capacity needs. However, because of its importance on refinery energy consumption an overall assessment has had to be made. This has been considered separately from product quality changes.

The assessment of future conversion needs for each demand scenario has been made utilising the following basis and assumptions:

- refinery crude mix and base conversion capacity availabilities remain unchanged from 1990 to give a constant fuel oil yield,
- refinery crude run levels were set to meet OECD Europe demand, adjusted to reflect traditional product imports/exports,
- the difference between the projected fuel oil production and demand was then used to determine future fuel oil conversion needs.

In the "Fuel Oil Decline" scenario, in which the percentage of fuel oil falls by one third from 18% to 12%, the lower fuel oil production requires increased conversion capacity with the production of additional low cetane distillate components as a consequence. For the purposes of this study it has been assumed that a 2 cetane number improvement would be necessary in the period 1995 to 2000 to maintain the distillate pool cetane constant. A further correction (+3.5 relative to the base year 1990) proportional to the progressive increases in thermal cracking/cat cracking capacity needs, has been assumed for the period 2000 to 2010.

For the "Sustained Growth" scenario, in which the percentage of fuel oil is constant at 18%, the projected utilisation of thermal cracking/cat cracking capacity is lower than that shown for 1990 and therefore no distillate cetane correction has been assumed necessary.

To derive the net energy consumption CO_2 emission data for the future years, the relevant base energy data for 1990 have been increased to reflect changes in product demand and quality. The resulting figures have been adjusted in line with the refinery throughput and production forecast.

4. PERIOD 1980 TO 1990

Actual data (total and specific energy consumptions/CO_2 emissions)

This has been based on OECD/IEA data on fuel use in oil refineries shown in **Table 1** and the conversion factors shown in **Tables 2 and 3** from which:

- specific energy consumption in GJ/tonne of refinery input,
- specific CO_2 emission kg/t of refinery input,
- total refinery CO_2 emissions kt/year,

have been calculated and are shown in **Table 4**.

Impact of EU requirements for product quality changes.

Improved product quality requirements, such as reduced sulphur content in gasoil and the manufacture of unleaded gasoline, lead to an increase in refinery energy consumption.

To quantify the additional energy requirements, existing CONCAWE data on specific additional energy consumption[7,8,9] have been used together with the respective refinery data for the years 1980, 1985, and 1990.

Effect of conversion capacity changes.

Conversion capacity rose rapidly during this period as refineries adjusted to the reduction in heavy fuel demand, caused by the significant increase in crude oil prices seen in the 1970s and early 1980s.

The energy penalty for the additional conversion capacity utilisation during this period has been calculated using the basis shown in **Section 3.**

Assessment of energy conservation measures.

The energy savings achieved by refineries during this period have been assessed from a series of biennial multiclient studies amongst a number of CONCAWE member companies, together with information from individual companies. The energy conservation achieved during the period 1980 to 1990 has been assessed at 21% relative to 1980 energy consumption.

The results are shown in **Table 5** (2 pages).

5. PERIOD 1991 TO 2010

Increases in energy consumption result from improved product quality specifications due to environmental legislation. An assessment of the additional refinery fuel consumption was made in line with the procedures outlined in **Section 4** using forecast refinery production levels obtained from published studies.[4,6]

Although outside the original terms of reference for the study, the forecast period was extended beyond the year 2000 to 2010 and the results are also shown in **Table 5** (2 pages).

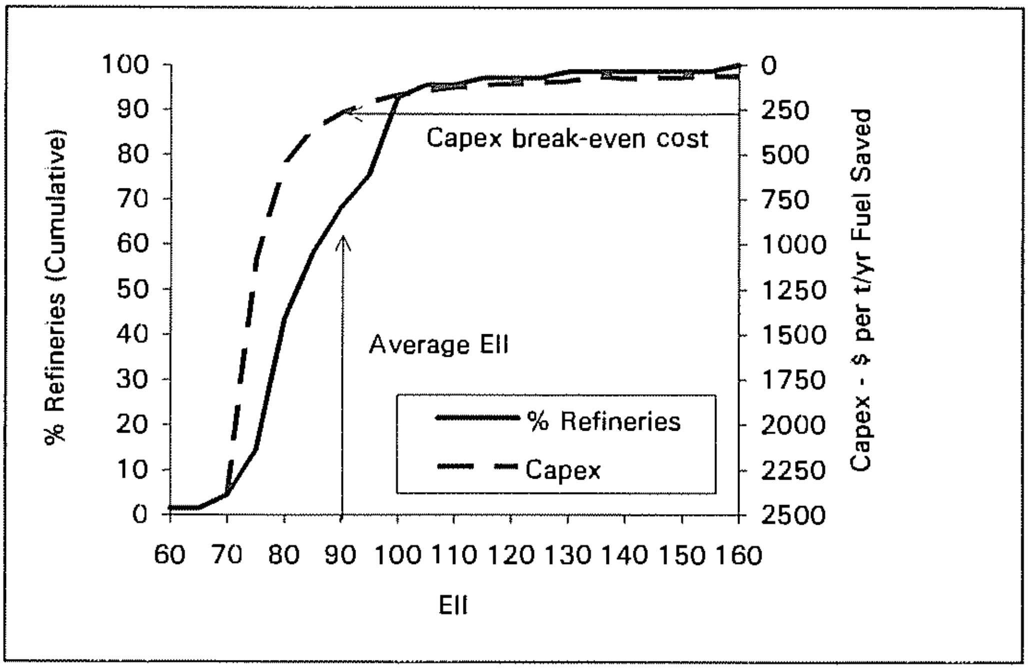
6. ENERGY CONSUMPTION IN REFINERIES.

Energy intensity indices (EII) were developed by Solomon Associates as a measure of the efficiency of energy use in their multi-client studies. EII of refineries based on 1990 operations, were taken from one such multiclient study.[3] They showed a range from 60 - 160 with the lower values representing greater energy efficiency; the weighted average was 88.

Capital investment costs (Capex) to achieve a reduction of 1 tonne fuel oil equivalent for a wide range of energy conservation projects show that investment costs per additional tonne of fuel saved increase exponentially with improving energy performance.

The EII and Capex data have been combined as shown in **Figure I**.

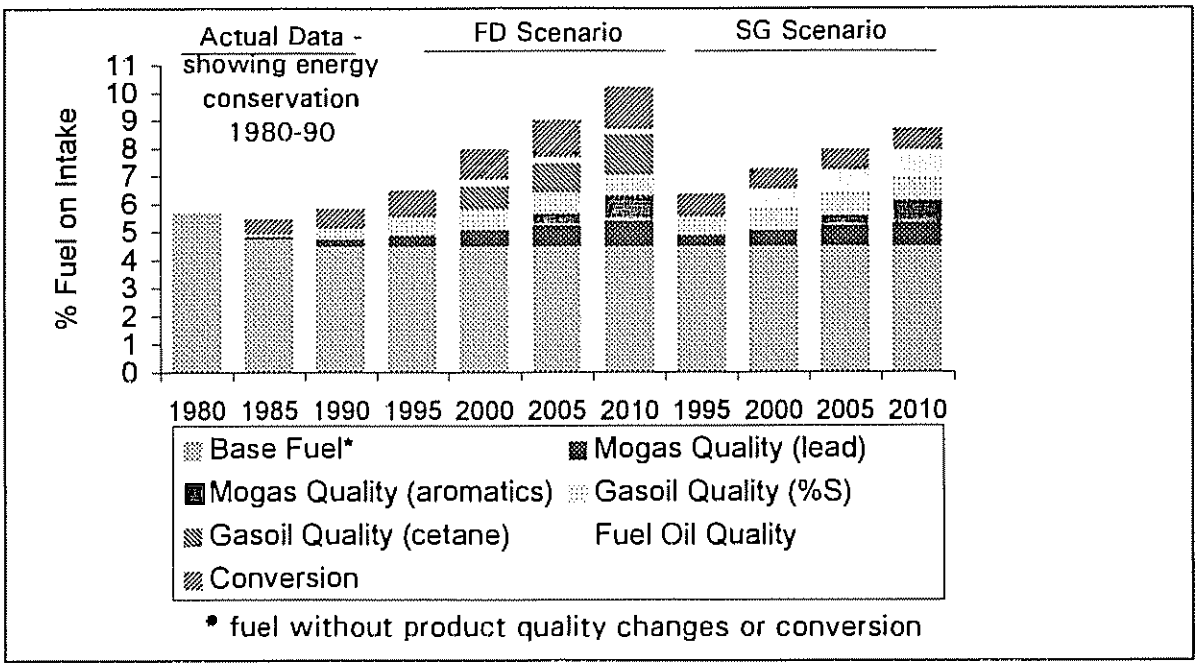
Figure I EII and Capex for Energy Conservation for Refineries



7. RESULTS

For the period 1980 to 1990, energy consumption in the European refining industry remained relatively constant, despite the continuation into the early 80s of the late 70s policy of substantial investment in energy conservation projects. Based on **Table 5**, **Figure 2** illustrates that without the implementation of energy conservation projects, specific energy consumption would have increased by about 23%. About half of this figure is attributable to an increase in conversion capacity utilisation as the refining industry invested and restructured in response to the demand for a lighter product barrel. The other half of the energy consumption increase is accounted for by the additional processing needed to meet mandatory changes in product quality, namely for lower sulphur gas oils and the introduction of low lead and unleaded gasoline grades.

Figure 2 Refinery Energy Consumption - Effect of Product Quality Changes and Conversion.



During this period CO_2 emissions, on a kg/tonne of refinery intake basis, decreased by 6% as a result of higher gas consumption in refinery fuel at the expense of heavy fuel oil. On an absolute basis, CO_2 emissions reduced by 12% as a result of this change in refinery fuel composition coupled with the reduction in refinery intake in 1990 relative to 1980.

As illustrated in **Figure 2** in the "Fuel Oil Decline" scenario, the refinery specific energy consumption is forecast to increase by some 75% from 1990 to 2010 while in the "Sustainable Growth" case the predicted growth over the same period is lower at 50%. These growth rates correspond to an increase in average energy consumption, expressed as a percentage of refinery intake, from 5.8% to 10.2% and 8.7% respectively. Over 50% of the additional energy identified for the FD scenario is associated with the increase in conversion capacity required and the correction of the consequential deterioration in distillate cetane quality from additional crackstock production. Improvements in gasoline quality, in particular the assumed reduction in benzene and aromatics levels post year 2000, account for a further 35% of the increase. The increase in conversion capacity needed for this scenario has reduced the need for fuel oil sulphur removal and therefore only limited additional energy requirements for residue desulphurization are shown.

Conversely in the SG scenario with its significant reduction in total oil demand over the period to 2010, essentially no further conversion capacity is needed and additional residue desulphurization capacity would be needed to satisfy the lower fuel oil sulphur requirements. Energy consumption in new residue desulphurization capacity makes up nearly 40% of the increase in this scenario with the gasoline quality changes a further 50%.

Whilst it is recognised that no set of energy conservation projects can fully represent the complete picture for all refineries, it is interesting to note from **Figure 1** that the weighted average EII for all refineries is coincident with the Capex economic breakeven cost based on the fuel costs and annual capital charge prevailing throughout the period up to 1990. This supports the view that following the oil price crises of the 70s, most of the economically feasible conservation projects were carried out in the 80s.

Figure 1 suggests that for two thirds of refineries further conservation projects would cost in excess of the breakeven cost. It is assumed that this group of refineries includes the modern, compact and highly integrated plant for which effective energy conservation was intrinsic.

For the remaining one third some potential to carry out further projects at below the breakeven cost is indicated. However, whilst there may be some potential it is assumed that this group includes the older individual plants which may also be widely dispersed spatially and consequently for which further energy conservation schemes could be very expensive.

An increase in CO_2 emissions of 75% over 1990 in absolute terms for the FD scenario is a direct result of the increase in refinery specific energy consumption. In contrast, for the SG scenario the increase in emissions due to the increase in refinery specific energy consumption is counterbalanced by a reduction in total refinery throughput leading to an increase in CO_2 emissions of 13% over 1990 in absolute terms.

8. CONCLUSIONS

During the 1980s refinery energy conservation measures more than compensated for the increases in energy use attributable to tightening of product specifications. CO_2 emissions also fell as a result of both energy conservation and a greater proportion of gas in the refinery fuel mix.

In the "Fuel Oil Decline" scenario, refinery fuel oil consumption is forecast to increase by 75% and CO_2 emissions by 65% relative to 1990 levels by the year 2010.

Similarly in the "Sustained Growth" scenario refinery fuel consumption is forecast to grow by 40% by year 2010 but CO_2 emissions would fall back, after a peak in year 2000, to be close to the 1990 levels by 2010 as total refinery throughput is assumed to decrease by 25%.

Following the extensive energy conservation measures in the 80s, it is considered that a limited potential for further economic energy conservation would have only a marginal impact on the growth in refinery energy consumption over the period up to 2010.

Any move to "greener" products, as a result of environmentally driven product quality legislation, will increase refinery energy consumptions and therefore CO_2 emissions. These increases in CO_2 emissions, and possible contribution to any potential enhanced greenhouse effect, need to form part of any deliberations on future product quality specification changes.

9. REFERENCES

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List of Tables

Table 1 Refinery Fuel Consumption and Refinery Intake for OECD Europe, Period 1980-1990

Quantity 10^3 metric tonnes

Refinery Fuels	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Refinery Gas	13 730	12 464	11 845	10 989	11 135	11 708	12 752	13 061	14 818	16 223	16 411
LPG	440	404	456	432	268	212	204	188	198	253	298
Gasoil	70	52	86	68	58	34	28	48	54	49	65
Naphtha	137	94	87	72	78	63	75	46	49	23	35
Residual Fuel Oil	19 019	16 382	15 375	13 485	11 873	10 618	11 375	11 244	11 068	10 883	10 515
FCC Coke	1 525	1 642	1 812	2 469	2 716	2 907	2 891	3 081	3 330	3 384	3 427
Misc Fuels	1 008	945	1 069	1 584	1 317	1 634	1 468	1 297	1 271	1 106	1 239
TOTAL	35 929	31 983	30 730	29 099	27 545	27 176	28 899	28 865	30 788	31 921	31 989
Refinery Input	653 981	591 978	559 955	553 638	555 873	540 248	578 070	572 624	598 340	598 665	613 210

Sources: Energy Statistics of OECD Countries 1980-1989/Quaterly Oil Statistics (1991)

Table 2: Petroleum Products-Average Heat Equivalents/tonne

Fuel	TJ/t
Refinery Fuel Gas	0.048148
LPG	0.047311
Naphtha	0.045008
Gasoil	0.043333
Heavy Fuel Oil	0.040193
Other Products	0.040193
FCC Coke	0.040193

Sources: Reference: 5

Table 3: CO_2 Emission Factors

Fuel	Emission factor t CO_2/t Fuel
Refinery Fuel Gas	2.51
LPG	2.51
Naphtha	3.18
Gasoil	3.18
Heavy Fuel Oil	3.22
Other Products	3.22
FCC Coke	3.22

Source: Reference: 5. 10

Table 4: 1980 to 1990 Refinery Energy Data and CO_2 Emissions

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Specific energy consumption GJ/t refinery input	2.41	2.38	2.41	2.33	2.24	2.28	2.30	2.30	2.35	2.44	2.38
Specific CO_2 emission, kg/t refinery input	164.1	161.5	163.8	159.1	152.6	153.2	154.7	153.3	154.8	158.8	153.8
Absolute refinery CO_2 emissions, 10^3 t/a	107 340	95 610	91 745	88 100	84 850	82 770	89 400	87 760	92 310	95 050	94 345

Table 5: 1980 -1990 Refinery Energy and CO_2 Emission

Energy penalties for OECD Europe relative to 1990 base

Scenarios from ADL study EU-12, scaled to OECD Europe

	Actual			FD scenario				SG scenario			
	1980	1985	1990	1995	2000	2005	2010	1995	2000	2005	2010
Total Call on Refineries (Crude + Fdst) Mt/y:	628.3	530.7	613.2	651	633	619	605	706	666	560	4[illegible]3
Naphtha/LPG/Gas	48.6	49.1	32.2	44	39	40	40	48	39	33	26
Gasoline/White Spirit	103.9	105.5	145.4	148	151	152	153	159	154	128	101
Kerosene	25.6	26.6	42.8	42	43	44	45	44	43	37	31
Diesel/Gasoil	202.6	192.6	205.2	233	224	220	216	247	230	194	1[illegible]8
HSFO	150.7	84.0	80.6	77	47	37	27	93	30	15	0
LSFO	31.0	14.0	26.9	26	47	45	43	31	91	87	[illegible]2
Others	29.8	30.7	36.6	38	38	39	39	38	34	29	[illegible]4
Refinery Fuel/Loss	36.1	28.2	43.5	43	44	43	42	46	45	38	[illegible]1
Total Fuel Oil, FO	181.7	98.0	107.5	103	94	82	70	124	121	102	[illegible]2
Calculations for ResHDS needs:											
HSFO (per '90 yield in Mt/y)	82.6	69.8	80.6	85.6	83.2	81.4	79.5	92.8	87.5	73.5	59.5
LSFO (per '90 yield in Mt/y)	27.6	23.3	26.9	28.6	27.8	27.2	26.5	31.0	29.2	24.5	19.9
Total FO (per '90 yield in Mt/y)	110.1	93.0	107.5	114.1	111.0	108.5	106.1	123.8	116.8	98.1	79.4
Extra Conversion (in Mt/y CCUeq)	-71.6	-5.0	0.0	11.1	17.0	26.5	36.1	-0.2	-4.2	-3.4	-2.6
Desulphur HSFO needed in Mt/y)	3.4	-9.0	0.0	-2.6	19.2	17.8	16.5	0.0	61.8	62.0	62.1
	< did not take place >										
GJ for ResHDS	0.0	0.0	0.0	-8.4	63.0	58.4	53.9	0.1	202.3	202.9	203.5
MJ/t Crude+Feedstock	0.0	0.0	0.0	-12.9	99.5	94.4	89.1	0.1	303.8	362.7	449.2
Calculations for Gasoil Pool:											
Automotive Diesel (Mt/y)	101.9	96.8	103.2	126.3	131.4	129.1	126.7	144.9	134.9	113.8	92.7
IGO/Marine/Other (Mt/y)	100.7	95.8	102.0	106.7	92.6	90.9	89.3	102.1	95.1	80.2	65.3
Gasoil Pool % S	0.41	0.35	0.23	0.12	0.07	0.07	0.07	0.11	0.07	0.06	0.05
Cetane in MJ/t Diesel	0	0	0	0	1648	2098	2898	0	0	0	0
~~Sulphur in MJ/t Gasoil~~	~~-506~~	-341	0	294	426	426	426	313	426	455	4[illegible]3
GJ for Diesel Cetane	0	0	0	0	217	271	367	0	0	0	0
GJ for Gasoil % S	-102	-66	0	69	95	94	92	77	98	88	76
GJ for Gasoil quality	-102	-66	0	69	312	364	459	77	98	88	76
MJ/t Gasoil	-506	-341	0	294	1393	1657	2126	313	426	455	4[illegible]3
MJ/t Crude+Feedstock	-163	-124	0	105	493	589	759	109	147	158	1[illegible]8

CCUeq= Catalytic Cracking Unit equivalents

	Actual			FD scenario				SG scenario			
	1980	1985	1990	1995	2000	2005	2010	1995	2000	2005	2010
Calculations for motor gasoline, mogas:											
Mogas RON/Lead (MJ/t)	-605	-303	0	291	583	830	1076	291	582	829	1076
Mogas Benzene/Aromatics (MJ/t)	0	0	0	0	0	750	1500	0	0	750	1500
GJ for lead	-63	-32	0	43	88	126	165	46	90	106	109
GJ for benzene aromatics	0	0	0	0	0	114	230	0	0	96	152
GJ for mogas quality	-63	-32	0	43	88	240	394	46	90	201	260
~~MJ/t Mogas~~	-605	-303	0	291	583	1580	2576	291	582	1579	2576
MJ/t Crude+Feedstock	-100	-60	0	66	139	388	652	66	135	360	574
Calculation summary for conversion:											
MJ/t Conversion intake	1678	1692	1793	1892	1904	1955	1945	1941	1922	1924	1927
MJ/t refinery intake	283	517	580	693	744	842	920	627	591	593	597
Difference vs 1990	-297	-63	0	113	164	262	339	46	11	13	17
Summary energy penalty (MJ/t):											
Gasoil Quality (Cetane)	0	0	0	0	342	437	607	0	0	0	0
Gasoil Quality (% S)	-163	-124	0	105	151	151	152	109	147	158	168
Fuel Oil Quality	0	0	0	-13	99	94	89	0	304	363	449
Mogas Quality (lead)	-100	-60	0	66	139	204	272	66	135	169	240
Mogas Quality (benz/arom)	0	0	0	0	0	184	379	0	0	171	334
Conversion	-297	-63	0	113	164	262	339	46	11	13	17
Total at 1990 efficiency	-560	-247	0	272	895	1333	1639	221	597	893	1208
Conversion Plant Intake kt/y:											
Thermal cracking	16 919	13 390	13 698	16 364	16 328	14 967	15 420	14 550	12 989	10 704	8 418
Visbreaker	23 498	54 287	59 268	73 972	73 798	67 287	73 798	65 290	57 823	49 054	40 285
Coking	7 867	9 702	13 447	13 897	14 691	14 691	14 691	12 353	12 243	10 202	8 162
Flexi-Coking	0	0	1 759	1 907	1 907	2 861	3 815	1 907	1 590	1 325	1 060
Cat Cracking	52 122	81 219	87 629	98 006	102 907	116 383	123 053	98 006	87 117	73 505	59 893
Residue Cat Cracking	0	0	4 885	5 605	5 917	8 875	11 211	5 605	4 983	4 204	3 426
Hydro Cracking	6 002	8 779	12 697	19 900	21 006	23 632	24 875	19 900	17 689	14 925	12 161
Mild Hydro Cracking	789	611	12 174	20 740	21 892	21 892	20 740	20 740	18 435	15 555	12 674
Residue Hydrocracking	0	0	0	1 474	1 556	2 334	2 948	1 474	1 310	1 105	901
Total intake (in CCUeq)	106 095	162 256	198 469	238 516	247 387	266 618	286 004	227 926	204 921	172 606	140 291
Total intake (kt/y)	107 197	167 987	205 557	251 866	260 002	272 921	290 551	239 825	214 179	180 579	146 979
Intake TC/CC units (kt/y)	100 406	158 598	180 687	209 752	215 548	225 064	241 988	197 711	176 744	148 994	121 243
% TC/CC on Total Conversion	93.7%	94.4%	87.9%	83.3%	82.9%	82.5%	83.3%	82.4%	82.5%	82.5%	82.5%