# sulphur emissions from combustion of residual fuel oil based on EEC energy demand and supply, 1980-2000

Prepared by the CONCAWE Air Quality Management Group's Special Task Force on Residual Fuel Oil Desulphurization (AQ/STF-28)

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## ABSTRACTS

An assessment has been made of the energy consumption and oil combustion related sulphur emissions in the period 1980-2000 for the EEC-10 countries. The possibility of further sulphur emissions reduction and its effects on cost and refining infrastructure are discussed.

Het rapport geeft een overzicht van het te verwachten energieverbruik en de van verbranding van vloeibare zwaardere brandstoffen afkomstige zwavel emissies, voor de tien landen van de EEC in de periode 1980-2000. De mogelijkheid van verdere beperking van de uitstoot van zwavel en het effekt op de kosten en de infrastruktuur van raffinaderijen worden behandeld.

Der Bericht untersucht für die EG-10 Länder den über die Zeitspanne 1980-2000 zu erwartenden Energieverbrauch und die aus der Verbrennung von schwerem Heizöl resultierenden Schwefelemissionen. Die Möglichkeiten einer weiteren Reduzierung der Schwefelemissionen und deren Auswirkungen auf die Kosten und Infrastruktur der Raffinerien werden diskutiert.

Une estimation de la consommation énergétique et des émissions de soufre liées à la combustion des produits pétroliers a été faite pour la période 1980-2000 et pour les 10 pays de la CEE. La possibilité de réduire davantage les émissions de soufre et les effets sur le coût et l'infrastructure du raffinage sont discutés.

Se ha realizado una estimación del consumo energético y de las emisiones de azufre relacionadas con la combustión del petróleo, para el periodo 1980-2000 para la CEE-10. La posibilidad de una mayor reducción de dichas emisiones y sus efectos sobre los costes e infraestructura del refino son también objeto de discusión en el mencionado informe.

E'stata effettuata una valutazione, per il periodo 1980-2000, dei consumi di energia e delle emissioni di zolfo connesse con la combustione di olio combustibile nei 10 paesi della CEE. Vengono, inoltre, analizzati la possibilità di una ulteriore riduzione delle emissioni di zolfo ed i suoi effetti sui costi e sulla struttura di raffinazione.

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## EXECUTIVE SUMMARY

An assessment has been made of the energy consumption and oil combustion related sulphur emissions in the period 1980-2000 for the EEC-10 countries. The possibility of further sulphur emissions reduction and its effects on cost and refining structure are discussed.

General trends are identified for the EEC-10 as a whole and there will be areas where conditions are different and therefore warrant additional study.

## KEY CONCLUSIONS

- Oil demand has dropped significantly between 1980 and 1983 and no further growth is predicted for the year 2000. Fuel oil demand will be no more than 50% of the 1980 level.

- Refinery crude oil runs will continue to decline on account of increased product and refinery blendstock imports.

- Refinery crude oil intake will contain a higher proportion of low sulphur crude, although the quantity will not increase, and there should be sufficient conversion capacity available to meet the lighter cut of barrel demand.

- Sulphur emissions from inland fuel oil in 2000 are reduced 57-68 percent compared with 1980 as a result of market forces.

- A reduction of inland fuel oil sulphur in 2000 to say 1%, would require massive investment ($US 3-6 x $10^9$) in Residue Desulphurization (RDS) units (13-25) and would have a disruptive effect on refining structure.

- A price increase for 1% sulphur fuel of $US 38-55/tonnes would be required to recover the cost, which would make such fuel uncompetitive with low sulphur coal and natural gas.

- These reasons together with the shrinking fuel oil demand makes large scale investment in RDS units highly improbable.

- The application of flue gas desulphurization to large power stations burning high sulphur fuel oil would give 40% of the sulphur emission reduction obtained from the RDS investment case and would most likely be a less expensive route to reduce sulphur emissions from oil combustion if required. Furthermore, this route can attain some 400 mg $SO_2/m^3$ flue gas as opposed to 1700 mg $SO_2/m^3$ possible from RDS.

## 0. SUMMARY

In view of the significant changes in energy patterns and oil product demand structure in the EEC since 1980, an assessment has been made of the energy consumption and oil combustion related sulphur emissions in the period 1980-2000 for the EEC-10 countries. The possibility of further sulphur emissions reduction and its effects on costs and refining infrastructure are discussed.

The study is restricted to identifying general trends within a framework of probable alternatives. It is recognized that there will be localities where conditions are different to the more general ones assumed here and there may be scope for additional locally orientated studies. The following are the main conclusions and trends that can be identified.

0.1 Two levels of oil demand from the market have been assumed within the overall energy demand (oil, coal, gas and nuclear) for the year 2000. The higher at 440 million toe is the reference case identified by the EEC Commission and is 16% below the 1980 level. The lower level at 380 million toe is considered to be more realistic by CONCAWE members and is 27% below the 1980 level.

0.2 When establishing the sulphur emission position from residual fuel combustion over the period 1980-2000 two important aspects come to light.

a) There is some 50% reduction in fuel oil demand between 1980 and 2000.

b) The proportion of low sulphur crude oil assumed to be processed in 2000 can be as high as 58% compared with 34% in 1980. The absolute quantity of low sulphur crude is not assumed to increase but the reduction in crude runs is assumed to be in terms of medium/high sulphur crude.

0.3 It is calculated that the significantly lighter cut of the barrel demand can be met in 2000 with the expected available conversion capacity.

0.4 Sulphur emissions from inland fuel oil grades are calculated to have already dropped from 5.3 million tonnes in 1980 to 2.8 million tonnes in 1983 and will continue to drop further to a range of 1.7 to 2.3 million tonnes in 2000, a reduction of 57 to 68 percent compared with 1980. This reduction from oil combustion resulting from market forces is well in line with the objective of the EEC Commission to reduce sulphur emissions from all energy sources in large combustion plant by 60%. However the reduction will not be evenly spread throughout the EEC.

0.5 Not withstanding the above favourable sulphur emission position, the average sulphur content of inland fuel oils is in the range of 2.1% to 2.8%. There will be significant variation in fuel oil sulphur content from country to country. It would be possible to segregate quantities of lower sulphur fuel oil for use in special sectors but this would increase the sulphur content of the remaining fuels and not reduce total sulphur emissions.

0.6 The sulphur emissions from fuel oil in 2000 are almost equally spread over the sectors, power stations, large users (above 50 $MW_{th}$) and small users (below 50 $MW_{th}$). If it would be considered to reduce the sulphur content in each of these sectors to maximum 1% (1700 mg $SO_2/m^3$ flue gas) by RDS a massive investment would be required viz. 13-25 RDS units, investment $US 3 to 6 x $10^9$.

Although sulphur emissions would be reduced by another 15-30% of the 1980 level, such an investment programme is considered highly improbable in a shrinking fuel oil market not only because of its sheer size and cost but because of its disruptive effect on the EEC refining infrastructure. It would be necessary to close residue conversion units e.g. visbreakers, to make available feedstock for the RDS units and then to correct resulting supply and demand imbalances.

It is calculated that an average of $US 38/tonne 1% sulphur fuel would have to be added to the price of 3.5% sulphur fuel to recover the RDS costs and since this is unlikely to take full account of the disruptive effects mentioned above this price increase could go to the maximum that can be calculated of $US 55/tonne.

0.7 Low sulphur fuel produced from RDS is unlikely to be competitive with natural gas and low sulphur coal long term and therefore there will be no economic incentive to invest in such units. In the event that new sulphur legislation would require additional amounts of low sulphur energy, there would be a further move away from residual fuel oil from EEC refineries resulting in reduced crude oil runs and plant closure and either an intensification of conversion to rebalance the cut of the barrel or an increase of distillate imports from outside the EEC.

0.8 An alternative control strategy which would avoid the above mentioned disruptive effects would be the application of flue gas desulphurization (FGD) to large power stations burning high sulphur fuel oil. This could effect some 40% of the sulphur emission reduction that could be obtained from the RDS investment programme, would give a significantly lower $SO_2$ concentration in the flue gas (some 400 $mg/m^3$ instead of 1700 $mg/m^3$) and most likely result in a lower cost per tonne sulphur removed although this latter needs to be verified by further study.

With respect to the fuel oil in the remaining sectors, it would be possible to segregate low sulphur and high sulphur grades. Although this would not reduce the sulphur emissions, it would at least provide the opportunity to allocate the low sulphur fuel to areas with high $SO_2$ emissions and the high sulphur fuel could be allowed in less critical situations and thus minimise the effect of the emissions.

0.9 The energy forecast data for this study was developed mid 1985 i.e. before the oil price collapse and before the Russian nuclear accident. Mid 1986 is considered to be too early to have a clear concensus on the effect of these events on oil demand in the coming years. While it cannot be excluded that some increase in oil demand will take place in the near future, the ranges of fuel oil demand and resulting emissions identified in this study are still considered to cover the situation in the year 2000.

## 1. INTRODUCTION

Since 1980, some significant changes have been seen in the energy packet of the EEC-10 in terms of oil, coal, gas and nuclear, and also in the product breakdown within oil. These changes have an effect on sulphur emissions and therefore an assessment has been made of such emissions from fuel oil combustion in the EEC-10 for the period 1980-2000. For this latter year it was necessary to make some estimates of the energy and product demand breakdown. Having such a sulphur emission position it is possible to discuss the effects e.g. cost-wise of possible reductions in such emissions.

## 2. OUTLINE OF APPROACH

The study has been carried out on a global basis i.e. the ten countries of the EEC (pre 1986) have been treated as one unit with respect to energy demand, oil refining capacity and product supply. This approach has the advantage of allowing relatively easy calculations to be made but the consequent disadvantage of having 100 percent flexibility for supply, segregation, blending and transport at zero cost. Repeated reference to this aspect is made throughout the report.

The following outlines the various steps taken to assess the sulphur emission position.

Step 1. Assess total energy demand for 2000 broken down in the main energy forms i.e. oil coal, natural gas, nuclear and others. Within the oil demand a breakdown is made of the individual product demand. The data for the assessments was obtained from the EEC and from the oil company members of CONCAWE.

Step 2. Oil demand is met by supply of products from refineries within the EEC-10 and product imports.

Step 3. EEC refined products are manufactured from crude oil and imported feedstocks.

Step 4. The sulphur content of the manufactured fuel oils results from the quality of the crude oil processed and the type of processing applied in the refineries.

Step 5. The assessments required for steps 2, 3 and 4 were based on data and views of the oil company members of CONCAWE.

Step 6. In order to establish a base line, similar data as above was prepared for the actual situation in 1980.

Step 7. An LP computer model was used to simulate the processing of crude oil and feedstocks though the available refining facilities to produce the product demand. This allows the identification of utilized refining capacity, the quality of products and whether there are any constraints to meet individual product demands.

Step 8. The sulphur emissions from inland fuel oil including refinery fuel are assessed over the period 1980-2000.

Step 9. The fuel oil demand is split into bunkers, powerstation use, large plant and small plant use, and the sulphur content of the fuel in the power station, large and small plant sectors is reduced to maximum 1% sulphur to assess what desulphurization capacity is required.

Step 10. Based on step 9 the costs of sulphur reduction are assessed.

## 3. ENERGY DEMAND AND SUPPLY

Discussion of Salient Issues connected with Data Collection Phase.

### 3.1 ENERGY FORECASTS

Clearly energy demand and the relative level of sulphur emitting energy forms such as oil and coal is one of the most important parameters to this study. Forecasting energy demand and breakdown for 2000 is difficult and leads to the necessity of establishing a range of forecasts.

The EEC has published forecasts which show a large range but have identified a reference level. The resulting level for oil demand for EEC-10 in 2000 is 440 million toe. The combined views of the oil companies participating in CONCAWE puts the comparable oil demand at 380 million toe. It was decided to use both levels as a starting point in this study. A summary of these forecasts is given in Attachment 1.

### 3.2 PRODUCT DEMAND BREAKDOWN

Scrutiny of data submitted showed quite some similarity on the percentage cut of the barrel breakdown and this was applied to both levels of demand. The details are shown in Attachment 2/3.

### 3.3 PRODUCT IMPORTS

In order to determine the demand on refineries some assumptions on finished product imports into the EEC-10 were made. Here also there is a difference of opinion between the EEC and the Oil Companies on the most likely import level in 2000. The main new factor in addition to imports is that there is a large amount of new refinery capacity being built in the Middle East oil exporting countries which will be surplus to own requirements. It is not clear how much surplus product will come to EEC as opposed to the Western and Far Eastern areas. EEC foresee a low level, the oil companies a higher level. It was decided to use two levels for this study viz. 35 and 70 million tonnes/year of main products split across the barrel in line with overall product demand. The difference between total demand and product imports gives the demand on refineries.

3.4 CRUDE OIL/FEEDSTOCK PROCESSING (ATTACHMENT 4)

Traditionally significant amounts of feedstocks - essentially atmospheric residues for upgrading, have always been imported into the EEC-10. There is a strong chance that by 2000, the suppliers of feedstocks will choose to retain the material for their own upgrading but in order not to disregard the possibility, 25 and zero million tonnes of high sulphur atmospheric residues as refinery feedstocks were assumed.

To establish the quality of the crude oil packet the following philosophy was used.

a) Crude quality is represented by three crude oils considered representative for low sulphur, medium sulphur and high sulphur types, viz. Brent, Light Arabian, Heavy Arabian.

b) It is assumed in 2000 that EEC will preferentially process own crude supplemented to some extent by close-haul African crudes all of which are low sulphur type to a level not exceeding the present situation. However it was felt that North Sea production by 2000 could be declining and that therefore a lower level of low sulphur crude processing should be assumed. It was decided to use two levels viz. 180 and 130 million tonnes of low sulphur crude processing.

c) The remainder of the crude oil requirement was deemed to be in terms of medium/high sulphur in a ratio similar to the present position.

It should be noted that in this approach, low sulphur crude processing is more or less independant of total demand and that the greater the demand for crude oil the higher the proportion of medium/high sulphur types i.e. low sulphur crude is not a fixed percent of total crude intake.

3.5 SUMMARY OF DEMAND AND SUPPLY 1980 - 2000

For the year 2000, there are two levels for total demand, 2 levels for product imports, 2 levels for feedstocks and 2 levels for low sulphur crude oil, giving in total 16 cases which are shown in Attachment 2. The position for 1980/83 based on actual data is also given in Attachment 2.

Comparison of the data gives rise to the following main comments.

a) There is a significant drop in demand on refineries in 1983 compared with 1980 (100 million tonnes or 20 percent) which is essentially in the fuel oil and to a lesser extent in the gas oil sectors. By the year 2000 the assumptions range from no further drop in refinery demand to a further drop of nearly 100 million tonnes. The net effect of these changes is a 50% reduction in fuel oil demand between 1980 and 2000.

b) Although total gas oil/diesel fuel does not change significantly, automotive gas oil demand grows significantly and the ratio AGO/IGO changes from 1:2.5 to 1:1.

c) The low sulphur crude processing does not change significantly in absolute terms between 1980 and 2000 but in 1983 and 2000 there is a large drop in high sulphur crude processing which means that in the period the sulphur intake is significantly lower than in 1980. As a result the percentage of low sulphur crude in the refinery intake is between 34 and 58% in 2000 compared with 34% in 1980.

The range of data used for this study is expected to provide a window within which there is a good chance that the actual year 2000 position will be included. It can also be used to predict trend effects for situations outside the so-called window.

## 3.6 REFINERY PROCESSING CAPACITY

It is a well established fact that there is a large surplus of primary distilling capacity in the combined EEC refineries so that this can never be a limiting factor. During the last decade there has been a significant decrease in the cut of the barrel demand for fuel oil and a concurrent increase in cut of the barrel demand for the higher value products such as gasoline, kerosine and gas oil/diesel fuels. This change in yield has been met largely by the installation of fuel oil upgrading facilities such as catalytic crackers, thermal crackers, and to a lesser extent cokers and hydrocrackers.

While the aim of all the processes is the same, i.e. the conversion of fuel oil to distillates, the magnitude of the effect differ and the properties of the remaining fuel oil components differ from process to process. In general there is a concentration effect in the fuel oils of carbon, metals and nitrogen and sulphur. There is also some removal of nitrogen and sulphur.

In order to estimate the sulphur content of fuel oil in 2000, an *estimate of the fuel oil upgrading capacity is required* in addition to the quality of the refinery intake. To come to such an estimate oil companies submitted data on the present day situation plus firm plans for new capacity minus firm plans, as known at the time, for shutting down capacity as part of a refinery capacity rationalization plan. There were some differences of opinion on this latter aspect and it was agreed to take an average view on rationalization for the future. The capacities used for this study are shown in Attachment 6.

Comparison of 2000 with 1980 shows a sharp decrease in primary distillation capacity (300 million tonnes) and as a consequence of firm closing complete "simple" refineries a decrease in platforming and HDS capacity. In the platforming case this loss is compensated by the assumption that semi-regenerative units are completely replaced by continuous catalyst regenerative units by 2000. For HDS units, loss in capacity is compensated by improved level of desulphurization.

There is an increase in vacuum distillation and fuel oil upgrading capacity.

## 3.7 LP COMPUTER MODEL

It was agreed to simulate the processing of crude oil and feedstocks through the refinery facilities to produce the required product demand by the use of an LP computer model. Three CONCAWE members offered to carry out such runs on the basis that they would use a well established model available in their own company but would not make available details on model building or content. In principle such a model simulates the operation of the different types of processes in terms of yield and quality of components for blending, feedstocks for further processing and energy requirements of the plants. Based on crude oil offered to the model, in this case three types, low sulphur, medium sulphur and high sulphur and the product demand and quality specifications, the model chooses operating and blending modes to give the best solution e.g. in terms of costs or profit. Since the same basic input would be used it was hoped that the results would be similar. There was good agreement between the three companies' LP models particularly taking account of the difficulties involved with forecasting a 2000 situation. Although 16 different demand cases were developed for 2000 it was agreed only to examine five in detail, representing extremes so that all other cases would fall in between. The chosen cases were 1980, 1983, 2000 (cases 1, 2, 5, 15, 16) as indicated in the following Table.

SUMMARY OF DEMAND/SUPPLY POSITION ($10^6$ T/YR)

| Year | 1980 | 1983 | 2000 | | | | |
|---|---|---|---|---|---|---|---|
| Case | | | 1 | 2 | 5 | 15 | 16 |
| Product demand | 518 | 435 | 440 | 440 | 440 | 380 | 380 |
| Product import | 6 | 28 | 35 | 35 | 35 | 70 | 70 |
| Demand on refineries | 512 | 407 | 405 | 405 | 405 | 310 | 310 |
| Low sulphur crude | 176 | 197 | 130 | 180 | 130 | 130 | 180 |
| Other crude | 326 | 190 | 275 | 225 | 250 | 155 | 105 |
| Feedstocks | 10 | 20 | Nil | Nil | 25 | 25 | 25 |
| Total intake | 512 | 407 | 405 | 405 | 405 | 310 | 310 |
| Output | | | | | | | |
| Gasoline and lighter | 118 | 115 | 123 | 123 | 123 | 96 | 96 |
| Middle distillates | 191 | 154 | 166 | 166 | 166 | 126 | 126 |
| Fuel oil | 148 | 92 | 67 | 67 | 67 | 47 | 47 |
| Others | 21 | 19 | 22 | 22 | 22 | 19 | 19 |
| Sub-total | 478 | 380 | 378 | 378 | 378 | 288 | 288 |
| Refinery fuel and loss | 34 | 27 | 27 | 27 | 27 | 22 | 22 |
| Total output | 512 | 407 | 405 | 405 | 405 | 310 | 310 |

Further specification limits were put on a number of product quality items to further standardize the output. These specification items are shown in Attachment 7.

## 4. SULPHUR EMISSIONS 1980 - 2000 RESULTS

To restrict the amount of data to reasonable proportions only the most important factors are discussed in the following sections.

### 4.1 REFINERY UTILIZATION TO MEET DEMAND

Product demand and quality specifications could be met in all cases. This in fact means that in combination with the assumed available crude and feedstocks, there is sufficient conversion capacity available in 2000. The cases where there is 100% utilization of conversion capacity, have the heaviest crude intake. With increasing proportion of low sulphur crude, less conversion capacity is required.

### 4.2 FUEL OIL SULPHUR CONTENT

The sulphur content of the fuel oil grades is given in the following Table.

SULPHUR CONTENT (WT%)

| Case | 1980 | 1983 | 2000 | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 5 | 15 | 16 |
| Inland fuel (incl. refineries) | 3.4 | 2.5 | 2.8 | 2.4 | 2.6 | 2.6 | 2.1 |

The average sulphur content of the fuel oils produced illustrates clearly in case 16 the effect of the high proportion of low sulphur crude coupled with a low product demand. It should be realized that significant differences from the average will occur from country to country due e.g. to different proportions of low sulphur crude oil being processed.

That the sulphur contents in 2000 are not even lower is due to the concentration effect of the highly utilized conversion capacity, although of course conversion plants do remove some sulphur from the system e.g. via the sulphur recovery facilities. In 1980 and to a lesser extent in 1983 there are still significant amounts of unconverted residues in the fuel oil pool. This is shown in Attachment 9 also by the higher densities and Conradson residues in 2000.

## 4.3 SULPHUR EMISSIONS FROM FUEL OIL COMBUSTION

A better illustration of the sulphur position is given by calculating the sulphur emissions on combustion of the fuels (assuming that there is no flue gas desulphurization being carried out e.g. in power stations) since this also takes into account the quantities of fuel oil being consumed.

SULPHUR EMISSIONS ($10^6$ T/YR)

| Case | 1980 | 1983 | 2000 | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 5 | 15 | 16 |
| Inland fuel (incl. refineries) | 5.14 | 2.42 | 2.13 | 1.87 | 2.05 | 1.56 | 1.27 |
| Inland imports | 0.18 | 0.35 | 0.21 | 0.21 | 0.21 | 0.42 | 0.42 |
| Total inland | 5.32 | 2.77 | 2.34 | 2.08 | 2.26 | 1.98 | 1.69 |
| Bunker fuel | 0.74 | 0.64 | 0.60 | 0.58 | 0.56 | 0.36 | 0.27 |
| Bunker imports | Nil | Nil | 0.18 | 0.18 | 0.18 | 0.35 | 0.35 |
| Total bunkers | 0.74 | 0.64 | 0.78 | 0.76 | 0.74 | 0.71 | 0.62 |

It is worth noting that bitumen production creates an important sulphur sink of 0.5 million tonnes of sulphur.

The sulphur emission position for the inland fuels is shown graphically in Attachment 10. Outstanding is the sharp fall in emissions that has already occurred between 1980 and 1983 (48%). There is a further fall predicted for 2000, so that depending upon energy forecast and crude oil quality, sulphur emissions in 2000 have dropped by 56-68 percent of 1980 emissions. The lowest emission cases in 2000 are those with the lowest demand (15, 16) and with the highest proportion of low sulphur crude (2, 16).

## 4.4 OPTIONS TO FURTHER REDUCE SULPHUR EMISSIONS

Proposals on sulphur emission control from the EEC have been focussed on large industrial plant (above 50 $MW_{th}$), e.g. to reduce sulphur emissions from all energy sources in this sector by 60% of the 1980 level. The results of this study indicate that for oil combustion at least, sulphur emissions are well in line with this requirement by 2000 on a general EEC basis as a result of market forces e.g. of oil demand and low sulphur crude oil availability.

However, within this overall position there will be areas where such a reduction cannot be met without incurring extra costs e.g. from investment in desulphurization plant. If notwithstanding the situation further sulphur reduction of fuel oil would be required, the costs of different alternatives can be assessed as follows.

The inland fuel demand has been split into three sectors large industrial consumers (above 50 $MW_{th}$) this sector includes refineries, small users (below 50 $MW_{th}$) and power stations. An estimate of the consumption in these sectors is shown below:

FUEL OIL DEMAND PER END-USE CATEGORY ($10^6$ T)

| Case | 1980 | | 2000 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | | 2 | | 5 | | 15 | | 16 | |
| | (a) | (b) | (a) | (b) | (a) | (b) | (a) | (b) | (a) | (b) | (a) | (b) |
| Power stations | 63 | 60 | 23 | 17 | 23 | 17 | 23 | 17 | 20 | 8 | 20 | 8 |
| Large ind. user | 44 | 43 | 20 | 20 | 22 | 22 | 28 | 28 | 16 | 16 | 17 | 17 |
| Small users | 41 | 40 | 20 | 20 | 20 | 20 | 20 | 20 | 18 | 18 | 18 | 18 |
| Bunker fuel | 21 | 21 | 22 | 17 | 22 | 17 | 22 | 17 | 19 | 9 | 19 | 9 |

(a) Market demand
(b) Demand on refineries which allows for net fuel oil imports

It is now possible to consider reduction of sulphur emissions in these sectors by application of a number of alternative routes which are discussed below.

It would be possible to produce quantities of low sulphur fuel for use in a particular sector, but withdrawal of such from the fuel pool will increase the sulphur content of the remaining fuel oil and, therefore, there would be no effect on sulphur emissions.

Increasing the amount of low sulphur crude at the expense of high sulphur crude would reduce the sulphur content of the fuel pool, but it is concluded that no significant additional amounts of low sulphur crude will be available above the range of 130-180 million tonnes already used in the study.

In the field of desulphurization there can be opportunities to pretreat vacuum distillates and/or solvent extracted oils as conversion feedstocks. These routes would not have a significant overall effect on sulphur emissions, although locally they may provide a useful improvement and, therefore, have not been further considered in this study.

4.4.1. Residue Desulphurization (RDS)

Residue desulphurization is an option to be considered. As previously explained there are relatively small amounts of atmospheric residue available for desulphurization as fuel oil components since they have a higher value as conversion feedstock and, because of the abundance of low sulphur residues with low metals/asphaltenes content, it will be difficult to justify desulphurization as a pretreatment for high sulphur residue as conversion feedstock.

Therefore, a calculation has been made on how much RDS capacity would be required when treating a mixture of medium and high sulphur vacuum residues to reduce the sulphur content of the fuel oil in each sector to 1%. This is equivalent to an emission of 1700 mg $SO_2/m^3$ and is about the lowest that can be achieved from vacuum residues. The results are shown in Attachments 11/12 and are summarized below:

| Sector | Power | Above 50 $MW_{th}$ | Below 50 $MW_{th}$ |
|---|---|---|---|
| RDS units (a) | 4-9 | 4-8 | 5-8 |
| Investment (b)(c) \$US $10^6$ | 1000-2300 | 1000-2000 | 1300-2000 |
| Operating cost(b)(c)\$US $10^6$/yr | 300- 900 | 300- 800 | 400- 800 |
| Reduction of sulphur emissions $10^6$t/yr | 0.24-0.51 | 0.25-0.49 | 0.28-0.49 |
| Resulting sulphur emissions $10^6$t/yr | 0.08-0.17 | 0.16-0.28 | 0.18-0.20 |

(a) unit capacity 4000 t/cd
(b) Cost estimate bases: 1985, Rotterdam
(c) based on data in the concurrent CONCAWE report which updates the costs of RDS

The overall effect of introducing 1% sulphur fuel oil into all sectors is a reduction of 0.8 to 1.5 million tonnes of sulphur emissions which is some 15-30% of the 1980 level and would bring the total reduction from 1980 of 56-68% by market forces to some 85%.

However, to achieve this further reduction a massive investment in RDS would be required viz. some 13 to 25 units of 4000 t/cd each at an investment cost of \$US 3300-6300 million and an annual operating cost of \$US 1000-2500 million. These effects are illustrated in Attachment 13.

Such an investment programme must be considered highly improbable in a shrinking fuel oil market. Apart from its sheer size, it is likely to have a disruptive effect on refinery infrastructure. In many cases there will be insufficient straight-run feedstock for the units, which would mean it would have to be withdrawn from other units such as visbreakers. The loss of distillates from such units might be compensated for by the conversion effect of the RDS units on an EEC-10 basis but it is highly unlikely that this would be possible at each refinery. This will result in additional costs to correct supply and demand imbalances which are very difficult to estimate and therefore operating costs can be expected at least at the top end of the range i.e. reflecting a low or even zero credit for the conversion effect. If these costs are reflected back on the 1% sulphur fuel produced it would mean that on average $US 38/tonnes would have to be recovered on top of the price of 3.5% sulphur fuel. This could well increase up to $US 55/tonnes in the case of zero credits being applicable.

This applies not only to the commercial user but also to the refinery operator.

It is highly unlikely that such fuel oil could compete with alternative low sulphur energy forms such as coal or natural gas. The current drop in oil prices will make oil more competitive with coal but it can be seriously questioned whether such a situation would prevail long enough to encourage investment in significant amounts of residue desulphurization capacity.

In the case that low sulphur fuel oil legislation would be introduced and RDS is not installed there will be a further reduction in fuel oil demand viz. a switch to low sulphur coal and/or natural gas which would result in a further reduction in crude runs (closure of refineries) and adjustments to the cut of the barrel by a variety of means such as, increased conversion, crude oil adjustment, increased distillate imports.

### 4.4.2 Flue Gas Desulphurization

Having concluded that massive investment in RDS is unlikely it is worth enquiring whether there are still any alternatives which would avoid the disruptive effects associated with RDS. The power station sector is emitting about 25-35% of oil based sulphur in 2000. Individual capacities are large say 300 MW electrical and larger and the sulphur content of the fuel is high e.g. 4%. This makes the power station sector very suitable for application of flue gas desulphurization (FGD). In general some 90% desulphurization can be achieved so that application to the power station sector would replace the need for 5 to 10 RDS units which individually can only achieve a lower rate of desulphurization.

This route gives some 40% of the calculated emission reduction from the use of 1% sulphur fuel. The $SO_2$ concentration in the desulphurized fuel gas would be close to 400 mg/m$^3$ which is significantly better than can be achieved with desulphurized fuel oil.

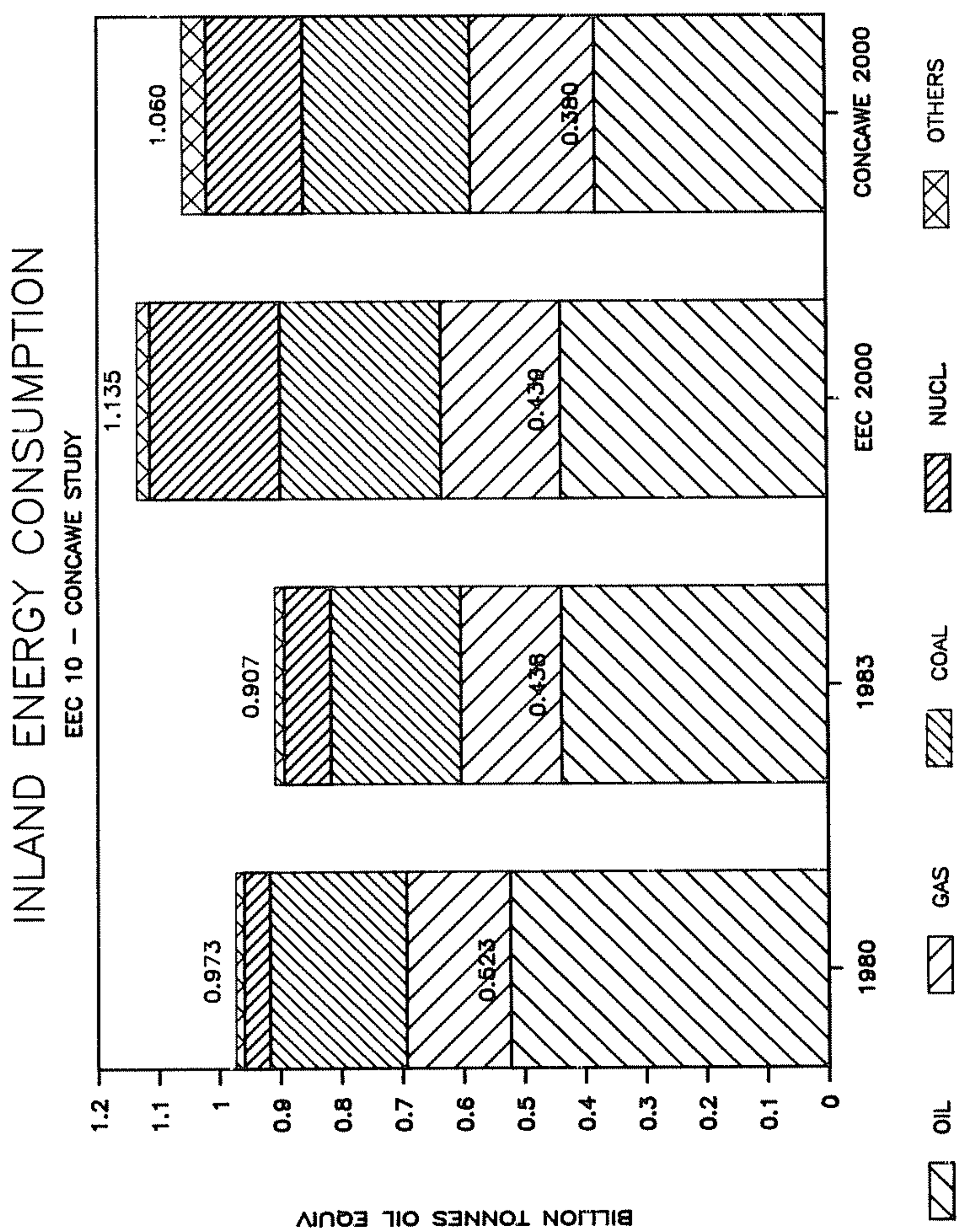
With respect to costs, the main experience is with coal-fired FGD, but based on miscellaneous cost data available it is likely that oil based FGD burning high sulphur fuel in large installations (above 300 MW electrical) is cheaper per tonne of sulphur removed than RDS. This needs to be verified by further study. In contrast, the cost of sulphur removal by FGD in smaller units (50-300 MW thermal) for example is quoted as $US 2600-4500/tonnes sulphur removed (CONCAWE report 7/84 "Cost of control of sulphur dioxide, nitrogen oxides and particulates emissions from large combustion plants in oil refineries").

With respect to the fuel oil in the remaining sectors, as mentioned before it would be possible to segregate low sulphur and high sulphur grades. This would of course not reduce the amount of sulphur emitted when burnt, but it would allow the possibility to allocate the low sulphur fuel to locations where there is a large concentration of $SO_2$, leaving the high sulphur grades to be used in less critical areas.

EEC-10 TOTAL ENERGY DEMAND
(MILLION TONNES OIL EQUIVALENT)

| | Actual 1980 | Actual 1983 | Year 2000 | | | |
|---|---|---|---|---|---|---|
| | | | EEC Estimates | | Oil Company Estimates | |
| | | | Base Case | Range | Average | Range |
| Coal | 223 | 212 | 264 | 223-309 | 275 | 259-300 |
| Total oil (a) | 523 | 438 | 439 | 281-539 | 380 | 360-420 |
| Natural gas | 170 | 165 | 196 | 196-256 | 205 | 195-210 |
| Nuclear | 43 | 76 | 215 | 150-235 | 160 | 135-175 |
| Others | 14 | 16 | 21 | 21- 29 | 40 | 35- 45 |
| Total | 973 | 907 | 1135 | - | 1060 | - |

(a) Including refinery fuel and bunkers


INLAND ENERGY CONSUMPTION
EEC 10 - CONCAWE STUDY
BILLION TONNES OIL EQUIV
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.973
0.523
0.907
0.438
1.135
0.439
1.060
0.380
1980
1983
EEC 2000
CONCAWE 2000
OIL
GAS
COAL
NUCL
OTHERS

OIL DEMAND CASES - YEAR 1980 AND 1983

| | 1980 * | 1983 * |
|---|---|---|
| Total oil demand | 517.9 | 434.9 |
| Product imports | 5.8 | 28.4 |
| Total ref. demand | 512.1 | 406.5 |
| Feedstocks | 9.7 | 19.6 |
| Total crude | 502.4 | 386.9 |
| Low S crude | 176.0 | 197 |
| Medium S crude | 136.4 | 124.9 |
| High S crude | 190.0 | 65 |
| PROD. DEMAND ON REFINERIES | | |
| LPG | 13 | 12.4 |
| Gasoline | 88.5 | 87.4 |
| Kero | 25.3 | 23.5 |
| Naphtha | 16.3 | 15.1 |
| Total gasoil | 165.8 | 130.5 |
| Autom. gasoil | 44.5 | 46.5 |
| Other gasoil | 114.8 | 78.5 |
| Bunker gasoil | 6.5 | 5.5 |
| Total F.O. | 181.9 | 118.8 |
| Inland F.O. | 127.7 | 74.2 |
| Bunker F.O. | 20.6 | 17.6 |
| Inl. F.O.powerstation | 60 | - |
| Large ind. use | 28 | - |
| Small users | 39.7 | - |
| Ref. cons. + loss | 33.6 | 27 |
| Lub oil | 6 | 5.3 |
| Bitumen | 12.5 | 11.1 |
| Coke | 2.8 | 2.4 |
| Total | 512.1 | 406.5 |

* Used for LP runs

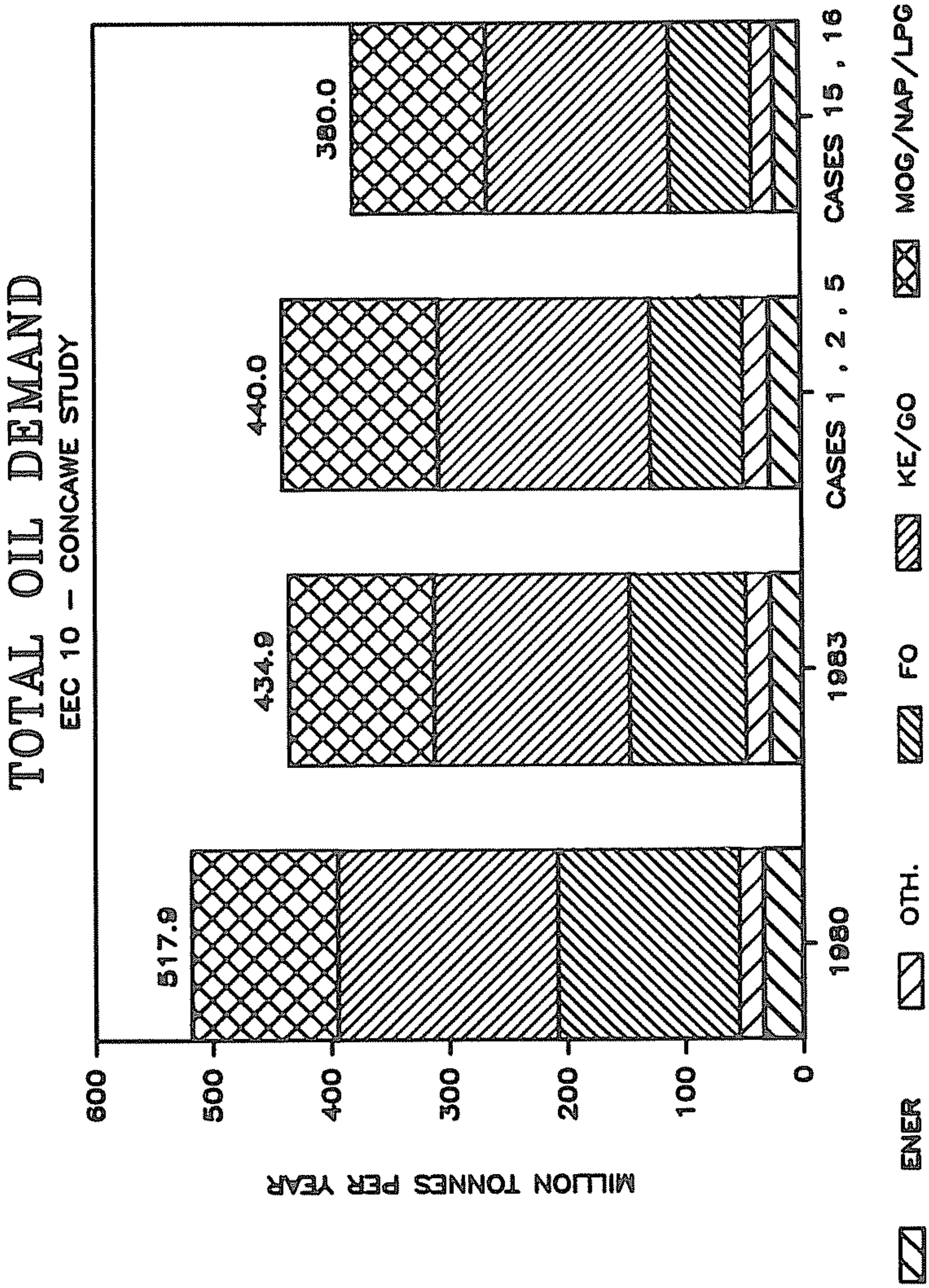
# OIL DEMAND CASES - YEAR 2000 ($10^6$ T )

| | EEC Reference Estimates | | | | | | | | Oil Companies Preferred Estimates | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1* | 2* | 3 | 4 | 5 * | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 * | 16 * |
| Total oil demand | 440 | 440 | 440 | 440 | 440 | 440 | 440 | 440 | 380 | 380 | 380 | 380 | 380 | 380 | 380 | 380 |
| Product imports | 35 | 35 | 70 | 70 | 35 | 35 | 70 | 70 | 35 | 35 | 70 | 70 | 35 | 35 | 70 | 70 |
| Total ref. demand | 405 | 405 | 370 | 370 | 405 | 405 | 370 | 370 | 345 | 345 | 310 | 310 | 345 | 345 | 310 | 310 |
| Feedstocks | - | - | - | - | 25 | 25 | 25 | 25 | - | - | - | - | 25 | 25 | 25 | 25 |
| Total crude | 405 | 405 | 370 | 370 | 380 | 380 | 345 | 345 | 345 | 345 | 310 | 310 | 320 | 320 | 285 | 285 |
| Low S crude | 130 | 180 | 130 | 180 | 130 | 180 | 130 | 180 | 130 | 180 | 130 | 180 | 130 | 180 | 130 | 180 |
| Medium S crude | 206 | 169 | 180 | 142 | 188 | 150 | 161 | 124 | 161 | 124 | 135 | 98 | 142 | 105 | 116 | 79 |
| High S crude | 69 | 56 | 60 | 48 | 62 | 50 | 54 | 41 | 54 | 41 | 45 | 32 | 48 | 35 | 39 | 26 |
| PROD. DEMAND ON REFINERIES | | | | | | | | | | | | | | | | |
| LPG | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| Gasoline | 91.5 | 91.5 | 95 | 95 | 91.5 | 91.5 | 95 | 95 | 79.5 | 79.5 | 83 | 83 | 79.5 | 79.5 | 83 | 83 |
| Kero | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Naphtha | 13.8 | 13.8 | 1.2 | 1.2 | 13.8 | 13.8 | 1.2 | 1.2 | 10.2 | 10.2 | (2.4) | (2.4) | 10.2 | 10.2 | (2.4) | (2.4) |
| Total gasoil | 143.7 | 143.7 | 129.0 | 129.0 | 143.7 | 143.7 | 129.0 | 129.0 | 122.1 | 122.1 | 107.4 | 107.4 | 122.1 | 122.1 | 107.4 | 107.4 |
| Autom. gasoil | 68.9 | 68.9 | 62.0 | 62.0 | 68.9 | 68.9 | 62.0 | 62.0 | 58.6 | 58.6 | 51.7 | 51.7 | 58.6 | 58.6 | 51.7 | 51.7 |
| Other gasoil | 68.8 | 68.8 | 62.0 | 62.0 | 68.8 | 68.8 | 62.0 | 62.0 | 58.5 | 58.5 | 51.7 | 51.7 | 58.5 | 58.5 | 51.7 | 51.7 |
| Bunker gasoil | 6 | 6 | 5 | 5 | 6 | 6 | 5 | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 4 | 4 |
| Total F.O. | 94.4 | 94.4 | 83.2 | 83.2 | 94.4 | 94.4 | 83.2 | 83.2 | 80 | 80 | 68.8 | 68.8 | 80 | 80 | 68.8 | 68.8 |
| Inland F.O. | 50 | 50 | 46 | 46 | 50 | 50 | 46 | 46 | 42 | 42 | 38 | 38 | 42 | 42 | 38 | 38 |
| Bunker F.O. | 17 | 17 | 12 | 12 | 17 | 17 | 12 | 12 | 14 | 14 | 9 | 9 | 14 | 14 | 9 | 9 |
| Inl. F.O. Power-station | 17 | 17 | 11 | 11 | 17 | 17 | 11 | 11 | 14 | 14 | 8 | 8 | 14 | 14 | 8 | 8 |
| Large ind. use | 13 | 13 | 14 | 14 | 13 | 13 | 14 | 14 | 11 | 11 | 12 | 12 | 11 | 11 | 12 | 12 |
| Small users | 20 | 20 | 21 | 21 | 20 | 20 | 21 | 21 | 17 | 17 | 18 | 18 | 17 | 17 | 18 | 18 |
| Ref. cons. + loss | 27.4 | 27.4 | 25.2 | 25.2 | 27.4 | 27.4 | 25.2 | 25.2 | 24 | 24 | 21.8 | 21.8 | 24 | 24 | 21.8 | 21.8 |
| Lub oil | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Bitumen | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Coke | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Total | 405 | 405 | 370 | 370 | 405 | 405 | 370 | 370 | 345 | 345 | 310 | 310 | 345 | 345 | 310 | 310 |

* Used for LP runs

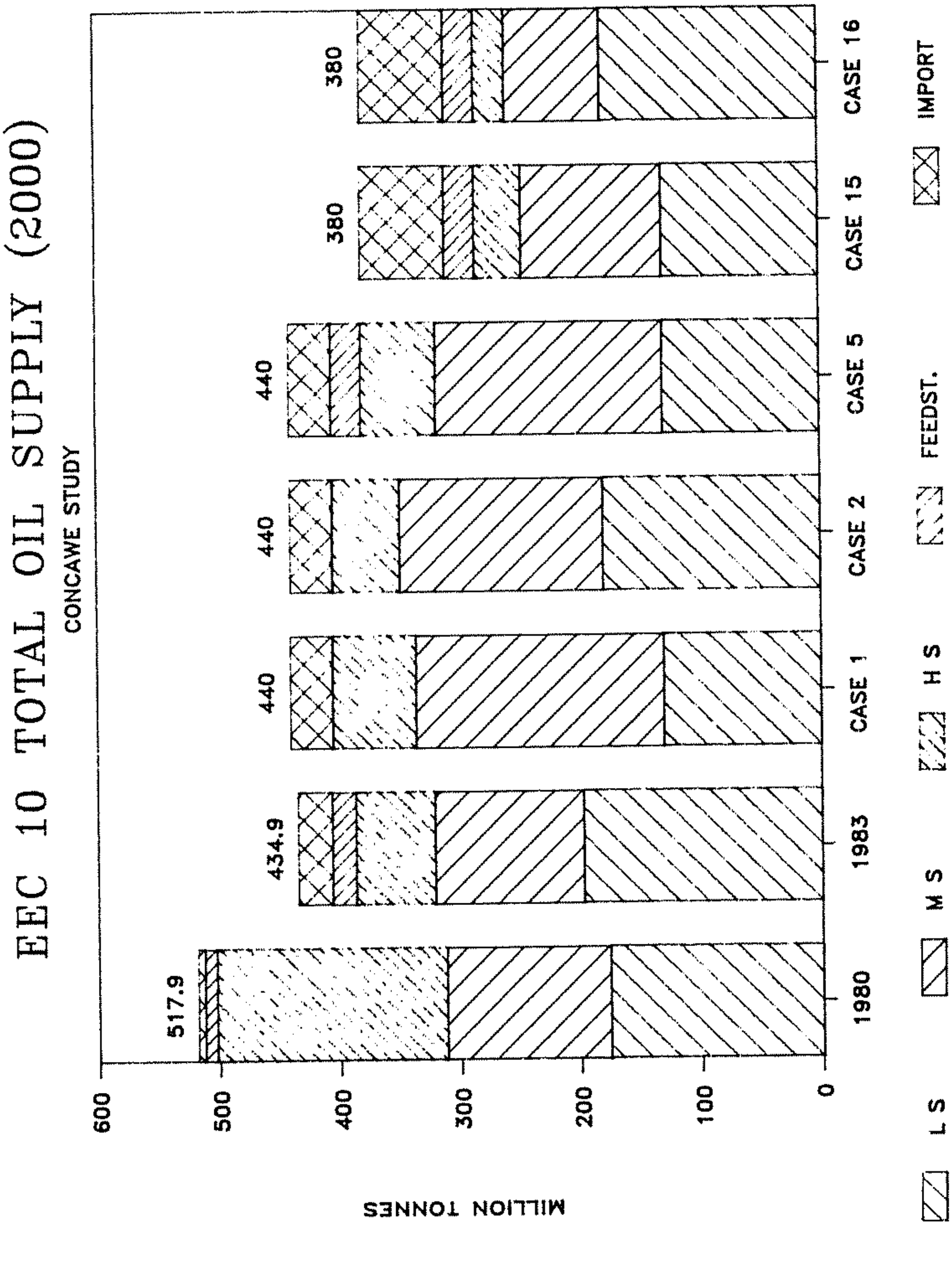
EEC-10 TOTAL OIL DEMAND
($10^6$ T)

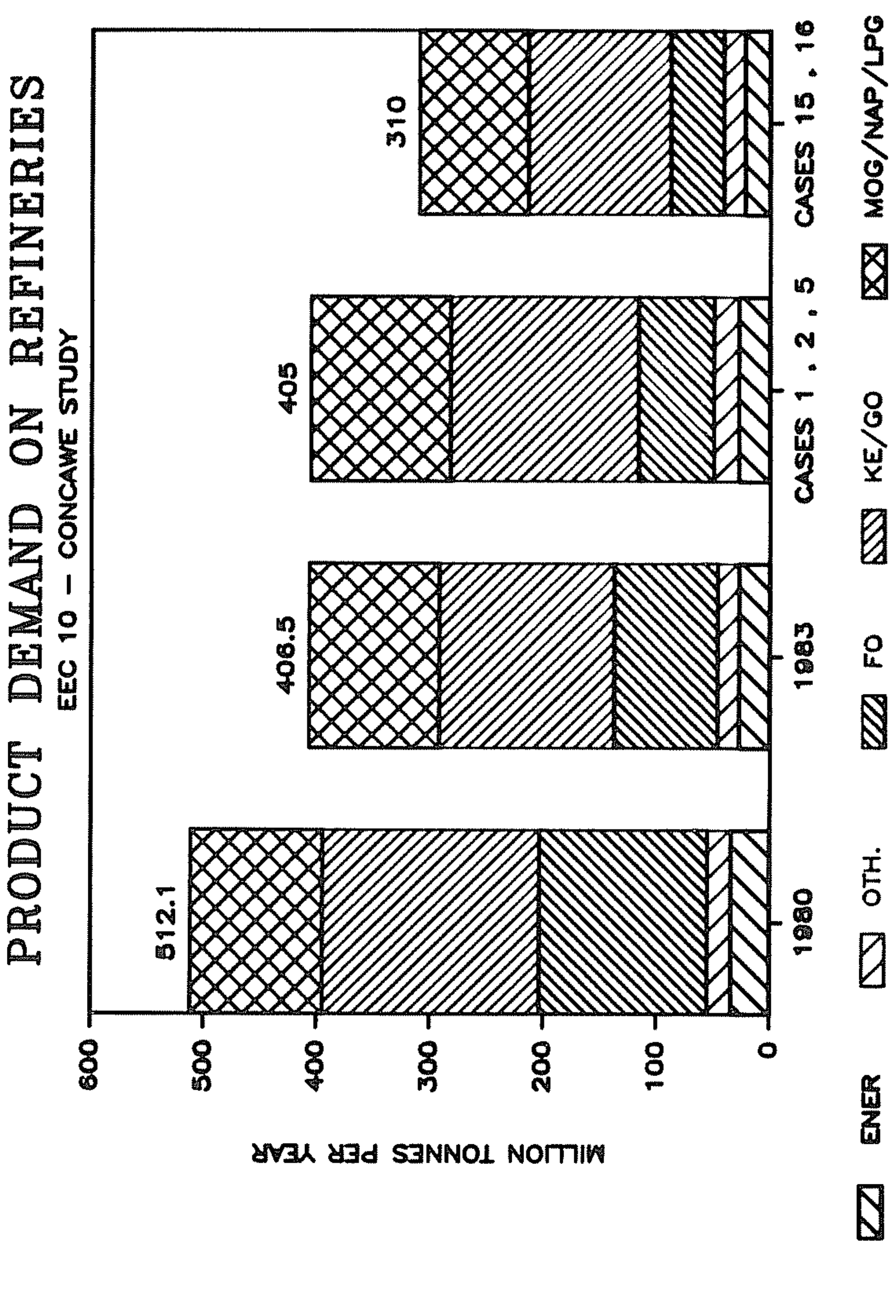
| | 1980 | 1983 | 2000 High Demand (EEC) | 2000 Low Demand (Oil Companies) |
|---|---|---|---|---|
| LPG | 15 | 16 | 18 | 15 |
| MOGAS | 84 | 84 | 88 | 76 |
| Naphtha | 25 | 23 | 27 | 23 |
| Kero | 20 | 19 | 22 | 19 |
| GO | 167 | 147 | 158 | 137 |
| AGO | 44 | 46 | 76 | 66 |
| industrial | 116 | 95 | 76 | 66 |
| bunker | 7 | 6 | 6 | 5 |
| Fuel | 153 | 98 | 78 | 69 |
| inland | 133 | 80 | 56 | 50 |
| bunker | 20 | 18 | 22 | 19 |
| Lub oil | 4 | 4 | 6 | 5 |
| Bitumen | 12 | 10 | 12 | 10 |
| Coke | 2 | 5 | 4 | 4 |
| Sulphur | 2 | 2 | | |
| Sub total | 484 | 408 | 413 | 358 |
| Refinery fuel | 34 | 27 | 27 | 22 |
| Total | 518 | 435 | 440 | 380 |

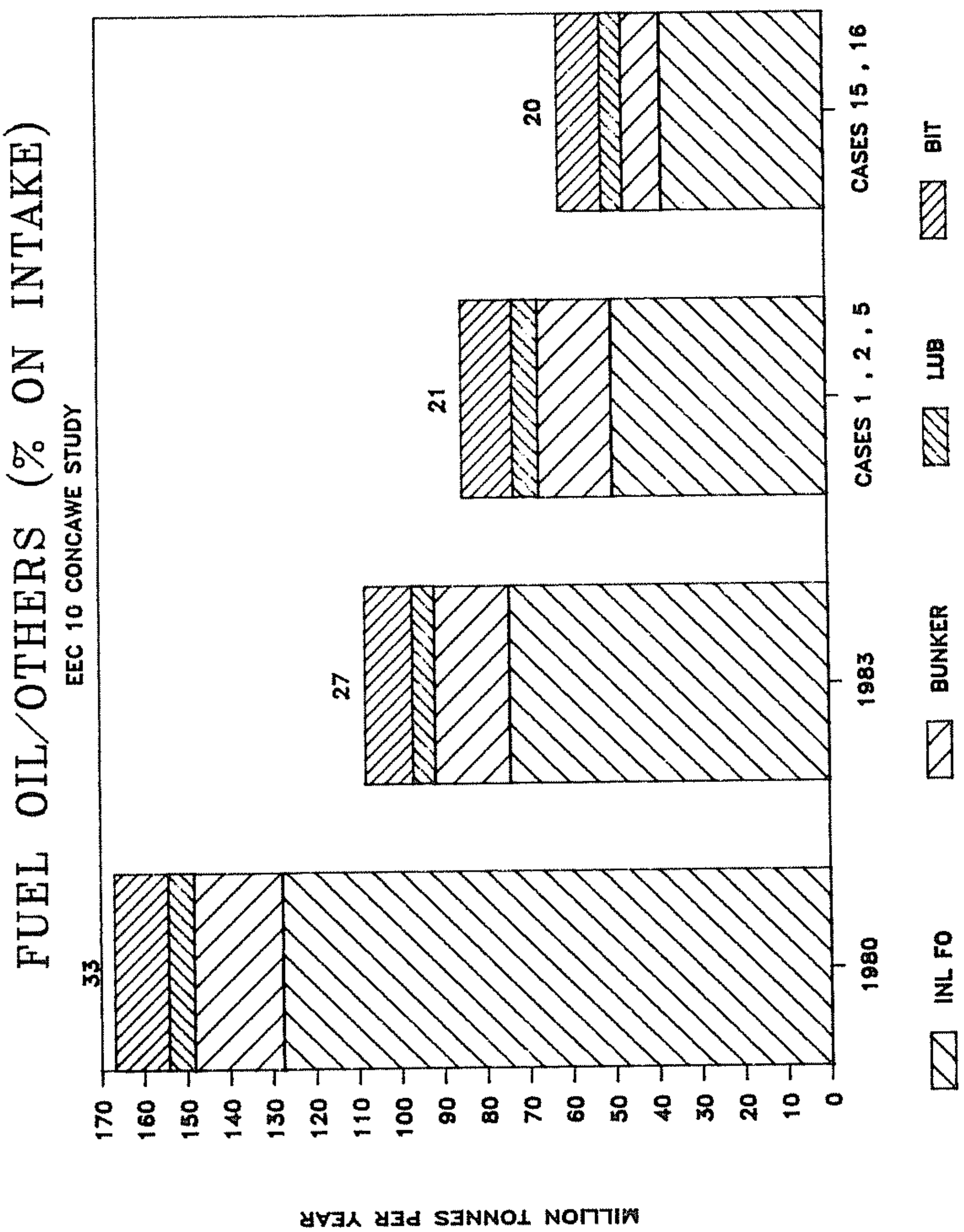

TOTAL OIL DEMAND
EEC 10 – CONCAWE STUDY
MILLION TONNES PER YEAR
600
500
400
300
200
100
0
517.9
434.9
440.0
380.0
1980
1983
CASES 1 , 2 , 5
CASES 15 , 16
ENER
OTH.
FO
KE/GO
MOG/NAP/LPG

TOTAL OIL SUPPLY ($10^6$ T )

| | 1980 | 1983 | 2000 | | | | |
|---|---|---|---|---|---|---|---|
| | | | Case 1 | Case 2 | Case 5 | Case 15 | Case 16 |
| Clean crude | | | | | | | |
| Total | 502.4 | 386.9 | 405 | 405 | 380 | 285 | 285 |
| LS crude | 176.0 | 197 | 130 | 180 | 130 | 130 | 180 |
| MS crude | 136.4 | 124.9 | 206 | 169 | 188 | 116 | 79 |
| HS crude | 190.0 | 65 | 69 | 56 | 62 | 39 | 26 |
| average API | 33.3 | 35.1 | 34.1 | 34.9 | 34.3 | 35.0 | 36.2 |
| average % S | 1.65 | 1.18 | 1.46 | 1.24 | 1.42 | 1.22 | 0.91 |
| Feedstocks for processing | | | | | | | |
| (370+ long residue) | 9.7 | 19.6 | 0 | 0 | 25 | 25 | 25 |
| Finished products Imports + stock change | 5.8 | 28.4 | 35 | 35 | 35 | 70 | 70 |
| Total | 517.9 | 434.9 | 440 | 440 | 440 | 380 | 380 |


EEC 10 TOTAL OIL SUPPLY (2000)
CONCAWE STUDY
MILLION TONNES
600
500
400
300
200
100
0
517.9
434.9
440
440
440
380
380
1980
1983
CASE 1
CASE 2
CASE 5
CASE 15
CASE 16
L S
M S
H S
FEEDST.
IMPORT


PRODUCT DEMAND ON REFINERIES
EEC 10 – CONCAWE STUDY
MILLION TONNES PER YEAR
600
500
400
300
200
100
0
512.1
406.5
405
310
1980
1983
CASES 1 , 2 , 5
CASES 15 , 16
ENER
OTH.
FO
KE/GO
MOG/NAP/LPG


FUEL OIL/OTHERS (% ON INTAKE)
EEC 10 CONCAWE STUDY
MILLION TONNES PER YEAR
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
33
27
21
20
1980
1983
CASES 1 , 2 , 5
CASES 15 , 16
INL FO
BUNKER
LUB
BIT

CAPACITY MAIN PROCESSING UNITS: EEC 10 ($10^6$ T/YR)

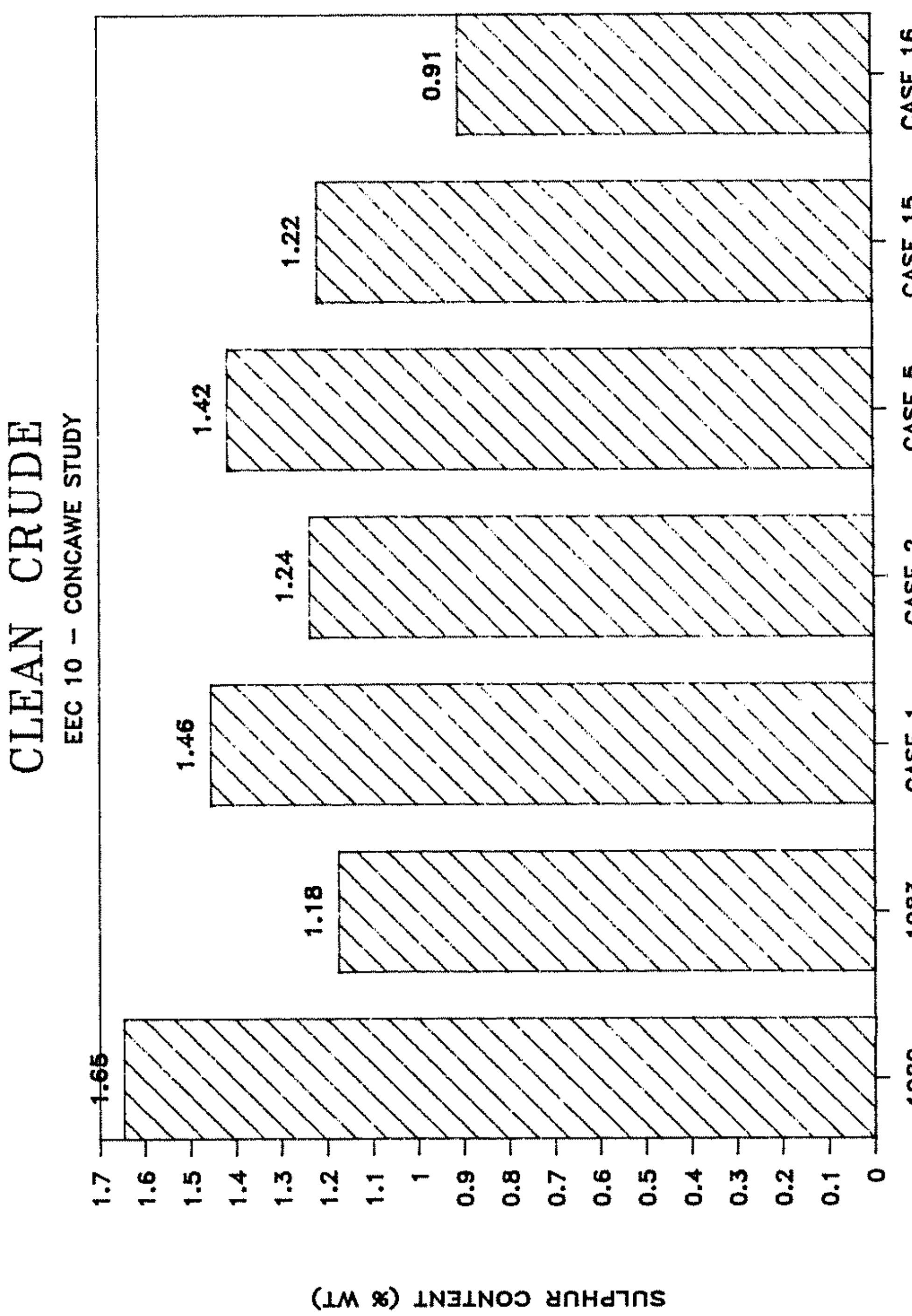
| | 1980 | 1983 | 2000 |
|---|---|---|---|
| Crude distiller | 829 | 642 | 535 |
| Thermal cracker (long residue) | 17 | 18 | 10 |
| High vacuum distiller | 179 | 203 | 210 |
| Cat cracker | 52 | 68 | 70 |
| Hydro cracker | 5 | 6 | 9 |
| Visbreaker (short residue) | 24 | 42 | 40 |
| Coker | 8 | 9 | 10 |
| Residue hydro conversion | nil | nil | 3 |
| Platformer | 93 | 79 | 73 |
| Alkylation | 3 | 5 | 5 |
| Isomerisation | 4 | 4 | 5 |
| Gas oil HDS * (nominal) | 136 | 126 | 100 |
| (usable) | 115 | 105 | 90 |
| % desulphurization | | | |
| straight run | 75 | 75 | 85 |
| cracked | 65 | 65 | 75 |
| Lub oil | 6 | 6 | 6 |
| Bitumen | 28 | 23 | 21 |
| Low sulphur long residue in FCC | nil | nil | up to 30% |

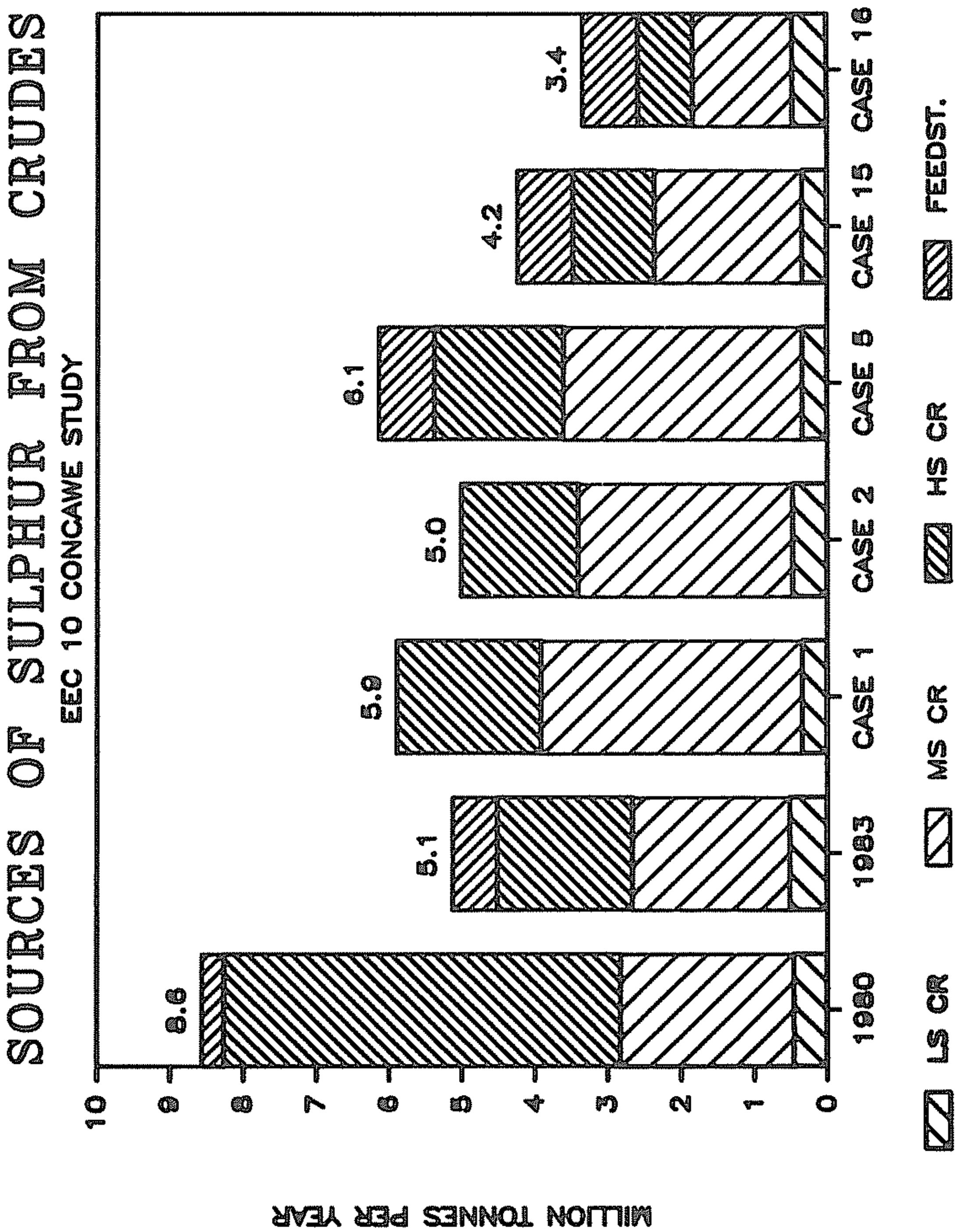
* max 20% LCO + cracked GO.

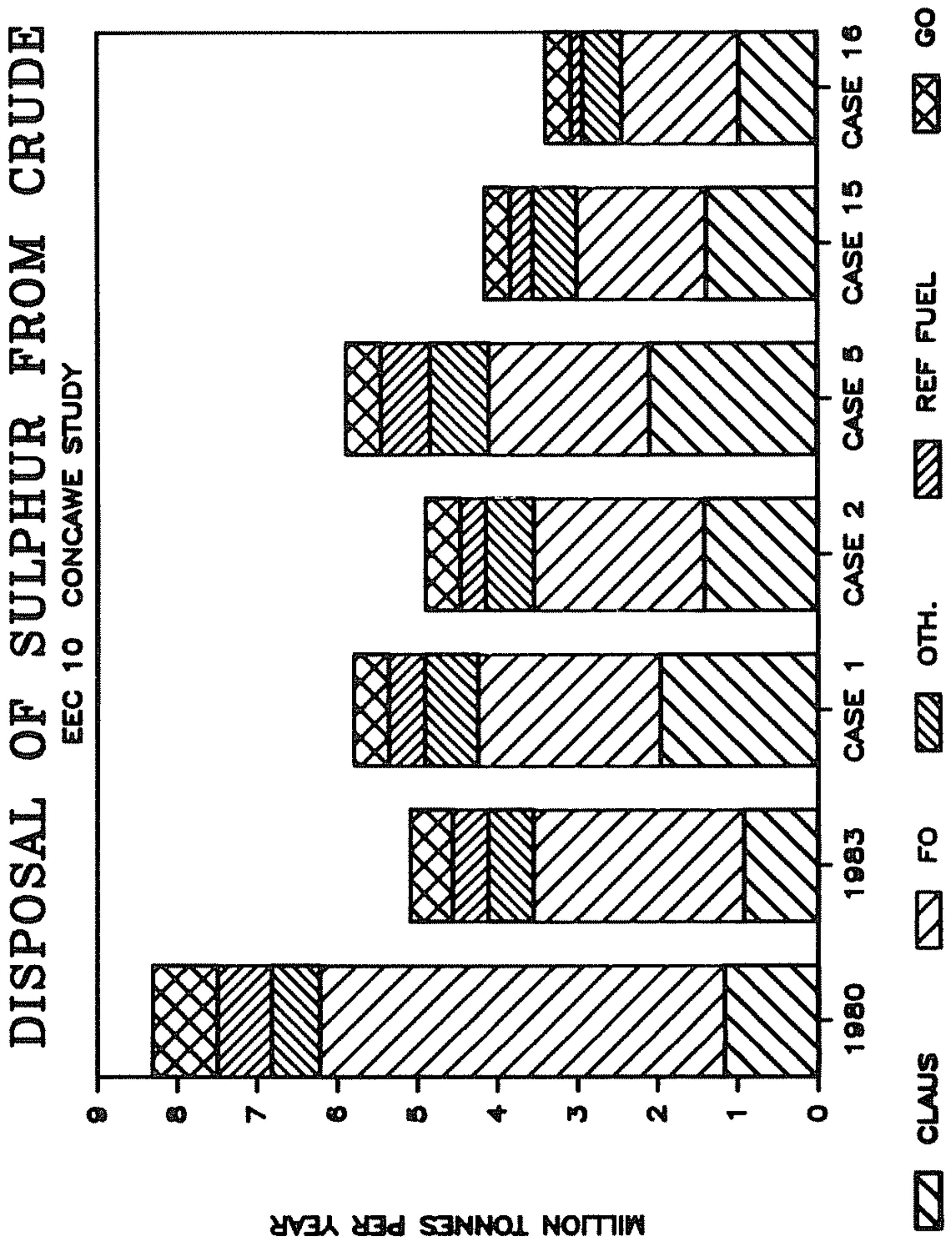
PRODUCT SPECIFICATIONS

| | | 1980-1983 | 2000 |
|---|---|---|---|
| LPG | | | |
| Gasoline | | | |
| lead max | | 0.4 | 0 |
| RON min | | 96.5 (75% prem/25% reg) | 95 |
| MON min | | - | 85 |
| RVP max | | 11 | 11 |
| Naphta | | - | - |
| Automotive GO | | | |
| density max | | 0.860 | 0.860 |
| S max wt % | | 0.5 - 0.4 | 0.3 |
| cloud point max | °C | 0 | 0 |
| cetane min | | 47 | 47 |
| Industrial GO | | | |
| S max wt % | | 0.5 - 0.4 | 0.3 |
| cloud point max | ° C | 0 | 0 |
| Inland fuel oil | | | |
| density max | | 0.995 | 1.05 |
| viscosity kinematic 100° C, max cS | | 40 | 40 |
| Bunker | | | |
| density max | | 0.995 | 0.995 |
| viscosity kinematic 100° C, max cS | | 40 | 40 |
| S max wt% | | 4 | 4 |
| Coke | | - | - |
| Lub oil | | - | - |
| Bitumen | | - | - |

Other quality parameters not limited

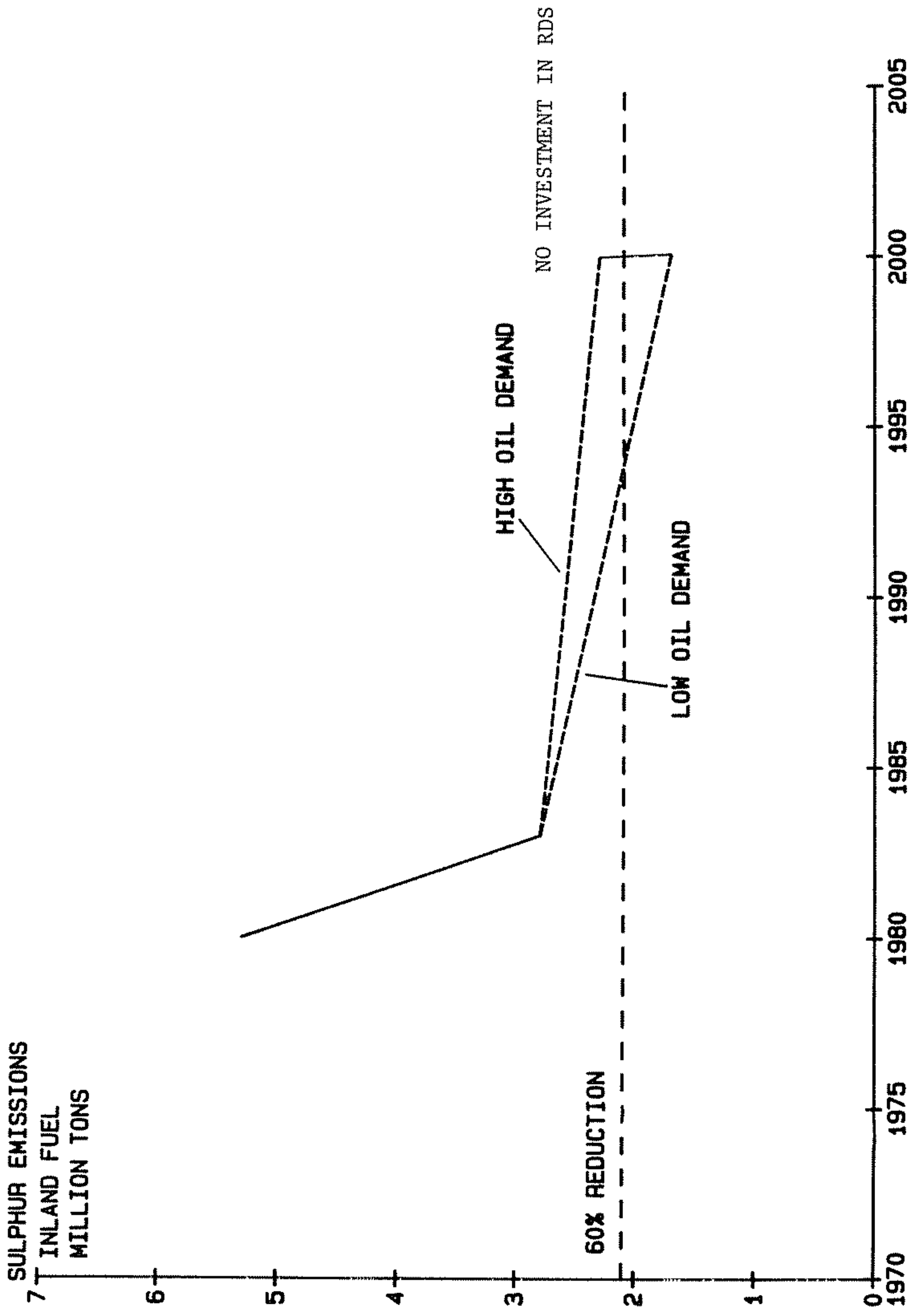

CLEAN CRUDE
EEC 10 - CONCAWE STUDY
SULPHUR CONTENT (% WT)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.65
1.18
1.46
1.24
1.42
1.22
0.91
1980
1983
CASE 1
CASE 2
CASE 5
CASE 15
CASE 16


SOURCES OF SULPHUR FROM CRUDES
EEC 10 CONCAWE STUDY
MILLION TONNES PER YEAR
0
1
2
3
4
5
6
7
8
9
10
8.6
5.1
5.9
5.0
6.1
4.2
3.4
1980
1983
CASE 1
CASE 2
CASE 5
CASE 15
CASE 16
LS CR
MS CR
HS CR
FEEDST.


DISPOSAL OF SULPHUR FROM CRUDE
EEC 10 CONCAWE STUDY
MILLION TONNES PER YEAR
0
1
2
3
4
5
6
7
8
9
1980
1983
CASE 1
CASE 2
CASE 5
CASE 15
CASE 16
CLAUS
FO
OTH.
REF FUEL
GO

COMPOSITION OF INLAND FUEL OIL POOL
EX REFINERY (EXCLUDING REFINERY FUEL)

| Case | 1980 | 1983 | 2000 | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 5 | 15 | 16 |
| | % | % | % | % | % | % | % |
| Cracked residue | 20 | 37 | 64 | 38 | 61 | 58 | 57 |
| Straight-run residue (atmos./VAC) | 68 | 48 | 17 | 47 | 26 | 19 | 23 |
| Cycle oil | 4 | 12 | 10 | 10 | 10 | 15 | 14 |
| Other diluent | 8 | 3 | 9 | 5 | 3 | 8 | 6 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Total $10^6$ t/yr | 128 | 74 | 50 | 50 | 50 | 38 | 38 |
| Density | 0.975 | 0.989 | 0.994 | 0.990 | 0.994 | 1.002 | 1.00 |
| Conradson | 12.4 | 13 | 16.7 | 13.5 | 14.8 | 16.7 | 14.4 |


SULPHUR EMISSIONS
INLAND FUEL
MILLION TONS
NO INVESTMENT IN RDS
HIGH OIL DEMAND
LOW OIL DEMAND
60% REDUCTION
0
1
2
3
4
5
6
7
1970
1975
1980
1985
1990
1995
2000
2005

EFFECt* OF 1% SULPHUR FUEL ON SULPHUR EMISSIONS IN 2000

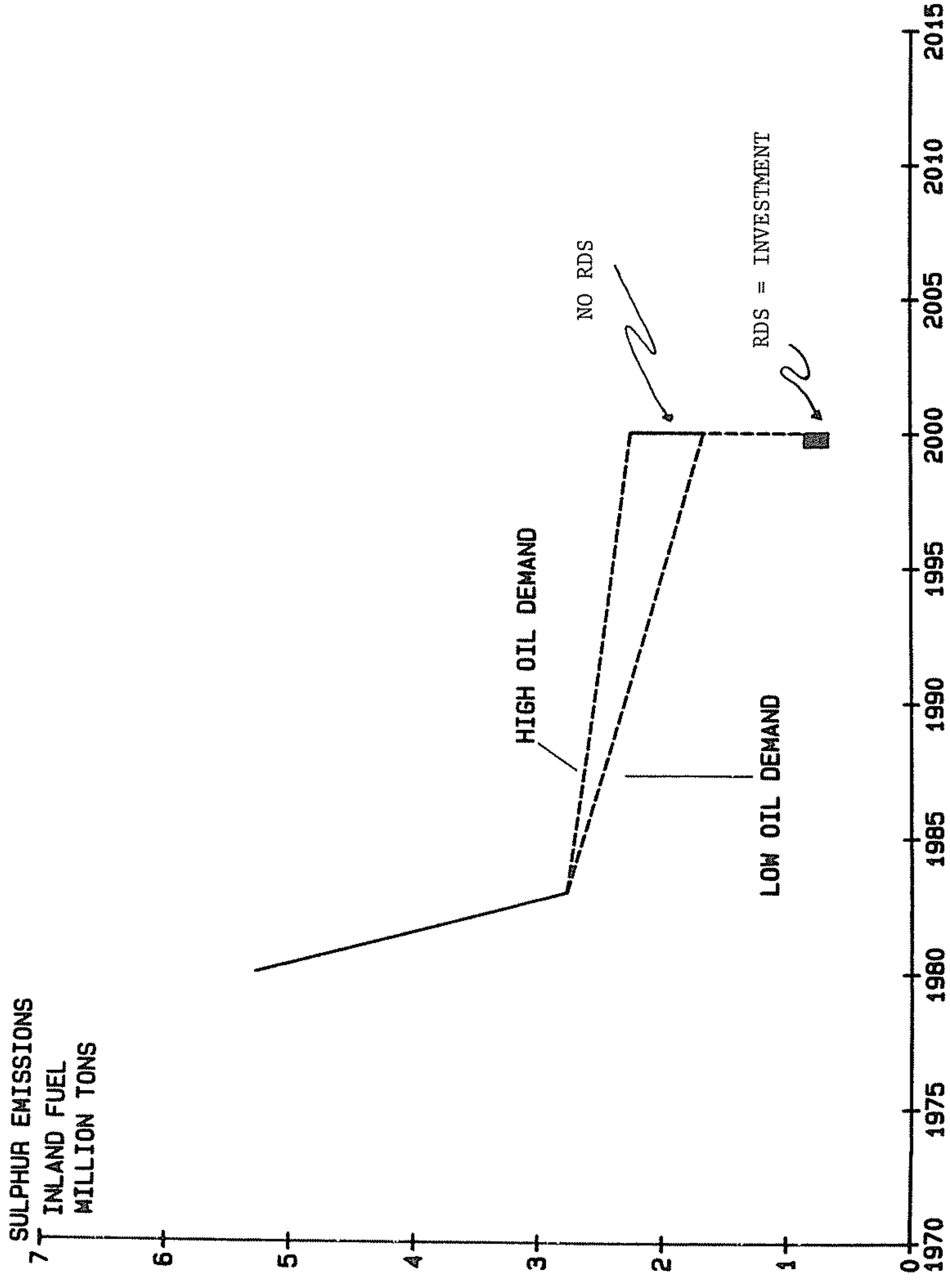
| CASE | | 1 | 2 | 5 | 15 | 16 |
|---|---|---|---|---|---|---|
| Product demand<br>low sulphur crude | | High<br>Low | High<br>Low | High<br>Low | Low<br>Low | Low<br>High |
| SECTOR<br>LARGE USERS (INCL. REFINERY LIQUID FUEL) | | | | | | |
| Fuel oil | $10^6$t | 20 | 22 | 28 | 16 | 17 |
| sulphur emissions | | | | | | |
| Base case | $10^6$t | 0.69 | 0.62 | 0.77 | 0.54 | 0.43 |
| 1% S | $10^6$t | 0.20 | 0.22 | 0.28 | 0.16 | 0.17 |
| Δ | $10^6$t | 0.49 | 0.40 | 0.49 | 0.38 | 0.25 |
| SMALL USERS | | | | | | |
| Fuel oil | $10^6$t | 20 | 20 | 20 | 18 | 18 |
| sulphur emissions | | | | | | |
| Base case | $10^6$t | 0.69 | 0.57 | 0.55 | 0.60 | 0.46 |
| 1% S | $10^6$t | 0.20 | 0.20 | 0.20 | 0.18 | 0.18 |
| Δ | $10^6$t | 0.49 | 0.37 | 0.35 | 0.42 | 0.28 |
| POWER STATIONS | | | | | | |
| Fuel oil | $10^6$t | 17 | 17 | 17 | 8 | 8 |
| sulphur emissions | | | | | | |
| Base case | $10^6$t | 0.68 | 0.68 | 0.68 | 0.32 | 0.32 |
| 1% S | $10^6$t | 0.17 | 0.17 | 0.17 | 0.08 | 0.08 |
| Δ | $10^6$t | 0.51 | 0.51 | 0.51 | 0.24 | 0.24 |
| ALL SECTORS | | | | | | |
| Fuel oil | $10^6$t | 57 | 59 | 65 | 42 | 43 |
| sulphur emissions** | | | | | | |
| Base case | $10^6$t | 2.06 | 1.87 | 2.00 | 1.46 | 1.21 |
| 1% S | $10^6$t | 0.57 | 0.59 | 0.65 | 0.42 | 0.43 |
| Δ | $10^6$t | 1.49 | 1.28 | 1.35 | 1.04 | 0.78 |

* This calculation is made on EEC-10 refinery demand. In addition imported fuel oil accounts for 0.2 to 0.4 million tonnes of sulphur.
Reduction to 1% for imports would give an additional sulphur emission reduction of 0.15-0.30 million tonnes.

** Small differences with the data reported in Sections 6.3 are due to solid refinery fuel not being included in the calculations.

RDS COSTS TO PRODUCE 1% SULPHUR FUEL OIL

| CASE | | 1 | 2 | 5 | 15 | 16 |
|---|---|---|---|---|---|---|
| Product demand | | High | High | High | Low | Low |
| low sulphur crude | | Low | High | Low | Low | High |
| SECTOR | | | | | | |
| LARGE USERS | | | | | | |
| Number of RDS units | | 8 | 7 | 8 | 6 | 4 |
| Investment | $US $10^6$ | 2000 | 1800 | 2000 | 1500 | 1000 |
| Operating costs | $US $10^6$/yr | 630 - 830 | 520 - 680 | 630 - 830 | 480 - 630 | 320 - 420 |
| SMALL USERS | | | | | | |
| Numbers of RDS units | | 8 | 6 | 6 | 7 | 5 |
| Investment | $US $10^6$ | 2000 | 1500 | 1500 | 1800 | 1300 |
| Operating costs | $US $10^6$/yr | 630 - 830 | 480 - 630 | 480 - 630 | 540 - 710 | 360 - 470 |
| POWER STATIONS | | | | | | |
| Number of RDS units | | 9 | 9 | 9 | 4 | 4 |
| Investment | $US $10^6$ | 2300 | 2300 | 2300 | 1000 | 1000 |
| Operating costs | $US $10^6$/yr | 660 - 860 | 660 - 860 | 660 - 860 | 310 - 410 | 310 - 410 |
| ALL SECTORS | | | | | | |
| Number of RDS units | | 25 | 22 | 23 | 17 | 13 |
| Investment | $US $10^6$ | 6300 | 5600 | 5800 | 4300 | 3300 |
| Operating costs | $US $10^6$/yr | 1920 - 2520 | 1660 - 2170 | 1770 - 2320 | 1330 - 1750 | 990 - 1300 |


SULPHUR EMISSIONS
INLAND FUEL
MILLION TONS
0
1
2
3
4
5
6
7
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
HIGH OIL DEMAND
LOW OIL DEMAND
NO RDS
RDS = INVESTMENT