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assessment of the energy balances and economic consequences of the reduction and elimination of lead in gasoline

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ABSTRACT

This report gives details of a study carried out at the request of the EEC Working Group: Evolution of Regulations - Global Approach (ERGA). The study assesses the impact of reducing or eliminating lead in gasoline and considers the ultimate situation, ten to fifteen years after the introduction of unleaded gasoline, when only unleaded gasolines are being manufactured. Computer models of refineries incorporating the latest refining technology are used to predict the optimum octane number for unleaded gasoline which will minimise total energy consumption. The report explores the variation of this optimum as the parameters of the base case are varied. The report also comments on the accompanying changes in gasoline composition and the way this will influence automotive exhaust emissions.

In dit rapport wordt een gedetailleerd verslag gegeven van een onderzoek uitgevoerd op uitnodiging van de EEG-werkgroep: Evolutie van Voorschriften - Benadering op Wereldniveau (ERGA). Vastgesteld wordt welke invloed vermindering van het loodgehalte in benzine of totale verwijdering van lood uit benzine heeft. Er volgt een bespreking van de uiteindelijke situatie tien tot vijftien jaar na invoering van de eerste loodvrije benzine, waneer uitsluitend nog loodvrije benzine zal worden geproduceerd. Met behulp van computermodellen van raffinaderijen waar volgens de modernste technologie wordt gewerkt wordt een prognose gesteld voor het optimale octaangetal van loodvrije benzine dat zal leiden tot een sterk terugdringen van het energieverbruik. Aan de hand van variaties van de uitgangsparameters worden verschillende waarden voor het optimale octaangetal onderzocht. Ook wordt commentaar geleverd op de hiermee gepaard gaande veranderingen in de samenstelling van benzine en besproken op welke wijze de samenstelling van uitlaatgassen van auto's hierdoor zal worden beinvloed.

Dieser Bericht enthält Einzelheiten über eine im Auftrag der EG-Arbeitsgruppe für die Entwicklung von Richtlinien auf weltweiter Ebene (ERGA) durchgeführte Studie. In dieser Studie werden die Auswirkungen der Absenkung sowie der gänzlichen Elimineung von Blei aus Ottokraftstoffen betrachtet wenn nach zen bis fünfzehn Jahren nach der Einführung von unverbleitem Benzin nur noch bleifrei Kraftstoff hergestellt wird. Mit Hilfe von Raffineriemodellen die den letzten technischen stand berücksichtigen wird die optimale Oktanzahl für unverbleites Benzin ermittelt. Der Gesamt-Energieverbrauch wird dabei minimiert. Es wird untersucht, welche Ahweichungen von diesem Optimalwert bei Veränderungen der dem Modell zugrunde liegenden Ausgangsparameter resultieren. Ausserdem wird auf die damit einhergehenden Änderungen der Benzinzusammensetzung und auf ihre Folgewirkungen für die Abgasemissionen von Kraftfahrzeugen eingegangen.

Ce rapport donne les détails d'une étude effectuée à la demande du groupe de travail de la ECC: Evolution de Règlementations - Approche Globale (ERGA). Cette étude évalue l'impact de la réduction ou de la suppression du plomb dans l'essence et examine la situation finale, dix à quinze ans après l'introduction de l'essence sans plomb, lorsque seules des essences sans plomb seront fabriquées. Des simulations sur ordinateur de raffineries utilisant les techniques de raffinage les plus modernes ont été utilisées pour prédire le degré d'octane optimal de l'essence sans plomb qui permettra de minimiser la consommation totale d'énergie. Le rapport examine les variations de cette valeur optimale en fonction des fluctuations des paramètres du cas de base. Le rapport commente enfin les modifications de la composition de l'essence qui s'ensuivent et leurs conséquences sur les émissions de gaz d'échappement des automobiles.

Este informe proporciona los detalles de un estudio realizado a petición del grupo de trabajo de la CEE: Evolución de Reglamentos - Aproximación Global (ERGA). El estudio evalua el impacto de la reducción o eliminación del plomo en la gasolina y pondera la situación final diez o quince años después de la introducción en el mercado de gasolina exenta de plomo, cuando solamente se fabrique este tipo de gasolina. Se utilizan modelos computerizados de refinerías, incorporando la tecnología más avanzada de refinado para prever el número óptimo de octanos de una gasolina exenta de plomo que pueda reducir al mínimo el consumo total de energía. El informe examina la variación de este valor óptimo a medida que varían los parámetros del caso base. El informe también comenta los cambios que se producen en la composición de la gasolina y la manera en que este fenómeno influirá sobre los gases que salen de los tubos de escape de los automóviles.

Il rapporto fornisce dettagli di uno studio eseguito su richiesta del Gruppo di Lavoro CEE: Evoluzione di Normative - Accesso Globale (ERGA). Lo studio procura valutazioni delle implicazioni della riduzione od eliminazione del piombo contenuto nelle benzine etilate, e fornisce considerazioni sulla situazione finale, dieci-quindici anni dopo l'introduzione delle benzine esenti da piombo, qualora si producano esclusivamente benzine non etilate. Avvalendosi dell'ausilio di elaboratori elettronici, vengono creati dei modelli di raffinerie impieganti le tecnologie di raffinazione più recenti, allo scopo di anticipare il numero di ottano ottimale per benzine non etilate, che riduca ad un minimo il consumo totale de energia. Inoltre si esamina la variazione di tale numero ottimale al variare dei parametri del caso base. Il rapporto contiene inoltre osservazioni concernenti i cambiamenti implicati riguardanti la composizione della benzina e l'influenza che ciò avrebbe sulle emissioni di gas di scarico degli automezzi.

CONTENTS

SUMMARY AND CONCLUSIONS

At the request of the EEC Working Group: Evolution of Regulations - Global Approach (ERGA) a study has been performed by CONCAWE to assess the impact of reducing or eliminating lead in gasoline. The study considers the ultimate situation, 10 to 15 years after the introduction of unleaded gasoline, when only unleaded gasolines are being manufactured.

The assessment has been made against a base case in which refineries, equipped with processes likely to be in common use at that time produce gasolines representing the average EEC 1983 market pattern containing 0.4 gPb/l. Therefore, it must be realised that neither the base case nor any of the scenarios reflect the current situation in any specific European country. The technical facilities assumed in the computer models are not representative of current refineries. Consequently, care must be taken in interpreting the results with respect to specific countries or with respect to any situation in the near future.

Using three different computer models of refineries incorporating latest refining technology the investigation led to the following conclusions concerning the production of low and unleaded gasolines: -

1. The optimum octane number for unleaded gasoline to minimise total energy consumption (taking into account both the fuel consumption of the vehicle and energy consumption in the refinery) is 94.5 RON/84.5 MON for a CEP = 1.0 (that is, for a Car Efficiency Parameter representing a 1.0% wt increase in gasoline consumption for each unit reduction in octane number). The total extra energy required at this optimum in comparison to the base case is 44 tonnes of crude oil/1 000 tonnes of gasoline.

   A single grade unleaded gasoline at the optimum octane number would not only provide firm guidance to the motor and petroleum industries, but would also considerably ease problems during the transition from leaded to unleaded gasolines.

2. The optimum octane number for unleaded gasoline for minimising the motorist's fuel costs is one octane number below the energy optimum. The extra cost at the cost optimum in comparison to the base case is 19 x 10^3 \$/1 000 tonnes of gasoline.

3. Energy requirements and cost both increase very steeply at an octane number of about 96 RON/86 MON. Above this level it rapidly becomes technically infeasible to produce a single grade gasoline in the necessary quantities.

4. The investigations have shown that the case with unleaded gasoline of 98 RON/88 MON premium grade quality in combination with a regular grade of 92 RON/82 MON is not a viable option. The maximum amount of this premium is 30% for one refinery configuration included in the study and significantly lower than this in the other models. The results show that many of the current refineries will be unable to manufacture this grade in any significant quantities, even after investment.

   When applying the results of this study to a dual grade market it must also be realised that neither the motor industry nor the petroleum industry have means to forecast and control the grade ratio in a dual grade system. Therefore, a dual grade system makes optimisation very difficult and dependent on customers' reactions. Also, the transition from leaded to unleaded gasoline would be much more complicated in a dual grade system.

5. Reducing the lead content from 0.4 g Pb/l in the base case to 0.15 g Pb/l without changing octane levels and grade split leads to an increased energy usage of 22 tonnes crude oil/1 000 tonnes of gasoline. The investments necessary to achieve this amount to 14-29 x 10^3 \$/1 000 tonnes of gasoline. However, it must be realised that these investments do not necessarily cover the same type of equipment required for the unleaded cases. Therefore this scenario cannot be considered as an interim step towards unleaded gasoline.

6. Moving to unleaded gasoline will change the composition of the gasoline, for example, the benzene and aromatics contents will be increased. At the current state of emission control this can negatively influence automotive exhaust emissions. Therefore, the introduction of unleaded gasoline may need to be combined with appropriate emission control measures, especially for hydrocarbon emissions.

7. All octane numbers mentioned in this study describe gasoline quality in the refinery. For guaranteed quality at the pumps appropriate margins must be subtracted. These vary from country to country.

1. INTRODUCTION

Private transport consumes a significant part of the total energy used in Europe (currently around 11%). Virtually all fuels currently used for private transport in Europe are derived from crude oil and the share on total crude oil utilisation (currently around 20%) is rising. Both spark-ignition engines, fuelled mainly by gasoline, and diesel engines fuelled by diesel fuel are used for private road vehicles. Gasoline-propelled vehicles account for more than 95% of private vehicles in Europe, the rest being mainly diesel-propelled vehicles.

One way of reducing fuel consumption in the passenger car is through engine design changes, but these may also affect gasoline quality requirements. Conversely, changes of gasoline quality and composition may require changes in engine design, which, in turn, may affect fuel consumption. Measures directed towards protection of the environment, i.e. emission control, which involve design changes in engines or associated equipment, or regulations affecting the composition of gasoline, i.e. the lead content, may lead to higher fuel consumption in the engine and also to the use of more crude oil in the manufacture of the gasoline. There is, therefore, a complex inter-relationship between total energy consumption, economics, gasoline quality, engine design and emission control.

At the request of the EEC Commission the ERGA Group (ERGA = Evolution of Regulations - Global Approach) is studying the possibilities for and the consequences of enhanced automotive emission control and of the reduction or elimination of lead in gasoline. CONCAWE has been asked by ERGA to provide information on the impact on energy consumption and the economic consequences of reducing or eliminating lead in gasoline. This paper provides this assessment.

2. OBJECTIVE AND METHODOLOGY

a) Scenarios

ERGA has defined a number of scenarios as shown in Table 1 for which information on the energy consumption and economic consequences has been requested.

Table 1: ERGA Scenarios

	0.4 gPb/l		0.15 gPb/l		0.0 gPb/l			
RON/MON	98/88	92/82	98/88	92/82	98/88	96/86	94/84	92/82
Base case	75%	25%						
ERGA scenario								
I			75%	25%				
II								100%
III							100%	
IV						100%		
V					max. poss.			balance

Details of the definitions of these scenarios, especially other quality characteristics of the gasoline, are given in Appendix I. These scenarios do not represent the eventual choice of alternatives but describe extremes which enable the consequences for any feasible solution to be assessed. In view of the importance of total energy consumption, CONCAWE has added information for the case at which total energy consumption is at a minimum - the so-called "optimum octane number". Also, preliminary studies indicated that no consistently valid information could be provided on the 98/88 - 92/82 (RON/MON) dual grade scenario (V). Therefore, CONCAWE decided to add another dual grade scenario in order to enable further analysis. This dual grade case considers a 96 RON/86 MON premium grade and a 92 RON/82 MON regular grade at the current grade split of 75:25.

It must be realised that neither the base case nor any of the scenarios reflect the current situation in any specific European country both with respect to grade splits and refinery facilities.

b) Assumptions

All investigations have been performed for the ultimate situation when the whole car population has been converted to the new grade(s). For all unleaded scenarios this situation will only be reached some 10 to 15 years after the introduction of cars designed to run on unleaded gasolines. No information has been developed in this report on the consequences and difficulties during the transition period. However, it should be recognised that the transition period will require careful examination.

CONCAWE has performed the investigation under the assumption of a constant mileage covered in all cases, expressing all results as differences in energy, cost etc. versus the base case for a mileage covered on 1 000 tonnes of gasoline in the base case. This approach, which provides directly comparable data has been used in previous studies and is explained in more detail in Appendix I.

Energy consumption and cost in each scenario is not only influenced by the need to replace, by more severe processing, the octanes lost by the reduction or removal of lead but also by the differences in the gasoline consumption of engines designed for various octane levels. The relationship between octane number and fuel consumption is described by the Car Efficiency Parameter, CEP (For details see Appendix I). A CEP of 1.0 wt % gasoline/octane number has been used in the calculations. Sensitivity studies for CEP 0.5 and 1.5 have also been performed.

One possibility to increase the octane quality of gasoline is the use of oxygenates such as methanol, TBA (Tertiary Butanol) or MTBE (Methyl-Tertiary-Butyl-Ether). Because of the limited availability of these components in Europe during the period in question, ERGA advised not to include the use of these components in the computations. Nevertheless, Appendix III provides relevant information as requested by ERGA.

c) Computations

CONCAWE has used three different computer models representing different conversion refineries. These allowed the use of the most modern refinery processes such as low pressure continuous catalytic reforming, hydrocracking etc. and incorporated latest advances in catalyst technologies, energy conservation techniques etc. Details of the underlying assumptions are provided in Appendices I and II.

In order to verify results, energy balances for the 94 RON/84 MON unleaded case vs the base case have been calculated by six other participants using the same underlying assumptions in their own computer models.

All octane numbers describe gasoline quality in the refinery. For guaranteeing quality at the pumps appropriate margins must be subtracted.

For those not familiar with the terms used in this report Appendix VI contains a glossary of terms.

3. RESULTS

All results are given as the average values of the three sets of results. Details regarding the variation of the individual results can be found in Appendix II.

a) Total Energy consumption

Figure 1 shows the results for total energy consumption and for total cost in graphical form. The octane number at which total energy consumption for private transport is at a minimum is 94.5 RON/84.5 MON. At this minimum the additional energy consumption vs the base case amounts to 44 tonnes of crude oil/1 000 tonnes of gasoline. Energy consumption increases very steeply at a pool octane number of about 96 RON/86 MON and it rapidly became technically infeasible to manufacture octane pools above this level in all three refineries. Regarding octane numbers, the study principally assumes a sensitivity of 10. However, especially at higher octane numbers sensitivity tended to exceed 10. In these cases, calculations have been based on the defined MON.

The information in Figure 1, refers to pool octane number, which is equivalent to a single grade. Appendix IV discusses the relationship between pool octane numbers and dual grade (premium/regular) systems.

As shown in detail in Figure 3 and discussed in Appendix II, the variation of results between the three computer models is relatively small. The individual curves are similar in shape and do not show any significant variation with respect to the optimum octane number. The check points at 94 RON/84 MON unleaded pool by 6 other participants confirm the validity of the results from the three computer models.

In comparison with previous CONCAWE studies (1) there are significant changes; the optimum octane number increased from 92 RON/82 MON to 94.5 RON/84.5 MON, and the respective energy debit decreased from 52 tonnes crude oil/1 000 tonnes gasoline to 44 tonnes crude oil/1 000 tonnes gasoline. These changes reflect the progress made in refinery technology from 1976 to 1983 both with respect to more energy efficient processes and with respect to more effective octane upgrading processes. The steep increase in crude oil prices during that period was the essential element in this development. It should also be remembered that the computer models already contain the latest technology, which is only just being introduced and will be the state of the art in the medium term. Significant refinery investment will be required in most refineries to reach this state.

Figure 2 gives the result of the investigations into the effect of various CEP values on total energy consumption. Reducing the CEP from 1.0 wt % gasoline consumption/octane number to 0.5 reduces the optimum octane number for minimum energy usage from 94.5 RON/84.5 MON to 93 RON/83 MON. An increase of CEP to 1.5 increases the optimum octane number to 95.5 RON/85.5 MON, which brings it close to the technically feasible limit. Further, total energy consumption increases with increasing CEP.

b) Costs

Figure 5 shows the additional investments required for the various scenarios together with the range of investments indicated by the three computer models. Investment progressively increases with increasing octane number.

Figure 4 shows the motorists' additional fuel costs due to the production of unleaded gasoline for the various cases.

As far as costs are concerned, all computations include those elements which are caused by the octane upgrading processes in the refineries and by the additional fuel consumption of cars at different octane levels. It does not include any elements reflecting additional cost for the distribution of unleaded gasoline nor does it include cost reflecting the changes of engines for emission control and different octane levels.

The optimum octane number for unleaded gasoline at a CEP = 1.0 for covering constant mileage at minimum motorists' additional fuel cost is about one octane number below the optimum for energy. The additional cost over the base case at this octane level is 19 x 10^3 \$/1 000 tonnes of gasoline. This figure includes the cost differences for the respective use of crude oil, the savings for eliminating lead alkyls and the capital charges for additional investment. Again the curve shows a very steep increase at around 96 RON/86 MON.

At the current consumption of gasoline in the EEC of about 80 x 10^6 tonnes per year, investments range from 1 120 x 10^6\$ to 4 560 x 10^6\$ and additional motorists' fuel costs range from 968 x 10^6\$ to 1 960 x 10^6\$ for the various scenarios.

c) Specific scenarios

Based on these computations, Table 2 contains all results requested by ERGA for the various scenarios and for the two additional CONCAWE cases. The differential values for total energy consumption and total cost for the unleaded single grade cases have been extracted from the information compiled in Figure 1.

For the dual grade scenarios, namely I, V and A, special computations have been performed, optimising refinery operations for each case. As far as Scenario V (dual grade at 98 RON/88 MON premium, 92 RON/82 MON regular) is concerned, the investigations indicate an availability of less than maximum 30% premium grade with 70% regular grade. Although the premium grade meets all of the quality characteristics defined by ERGA, the composition of this premium grade is rather unusual. Since the blending values used have not been verified for this composition, the results must be considered with caution. In any case it is important to note that even with investment many of the existing refineries will not be able to manufacture the 98 RON/88 MON premium grade at the 30% share, or even at all.

The differentials for refinery investments quote the range obtained in the three computer models. Necessary investment will depend very much on the specific situation of each refinery and, therefore, considerable variation below and above the ranges quoted in this study can be expected. It must also be realised that the refinery investment quoted for each scenario refers to significantly different equipment. At octane numbers below that of the base case, especially Scenario II, it represents equipment required to produce additional volumes of gasoline. In view of the current excess refinery capacity in Europe investment may not be required at most refineries for these cases. For the cases of octane numbers above the current unleaded pool octane number, i.e. Scenarios III, IV and V, investments mainly represent equipment required for upgrading octane quality. Excess capacity currently present in many refineries does not necessarily cover even parts of this investment as the appropriate type of upgrading process is essential. In fact the range of investments indicated in Table 2 may be on the lower side because many refineries in Europe are not equipped with the rather modern and efficient processes assumed in the Base Case of these computations.

d) Aromatics and benzene content

Table 2 also lists the differentials for the content of aromatics and benzene for the various scenarios, more details being included in Appendix II. The differentials have been calculated from the average values of the three computer models. Moving to higher octane pools in all cases increases the amount of aromatics and benzene. However, regarding current refinery structure in Europe the results of this study tend to understate the effect of lead reduction. Especially in hydroskimming refineries and refineries with small conversion capacity the increases both of the aromatics content and the benzene content will be significantly higher than indicated in Table 2.

e) <u>Scenario I</u>: Current gasoline quality at 0.15 g lead/1.

For Scenario I the investigations have shown that energy usage increases by 22 tonnes crude oil/1 000 tonnes of gasoline, cost increases by 12 x 10^3 $/1 000 tonnes of gasoline, and the additional investment ranges between 14 - 29 x 10^3 $/1 000 tonnes of gasoline. The investments required for this case to upgrade octane quality over the base case do not necessarily cover the same type of equipment as that required for unleaded gasoline. Therefore, from a technical/economic viewpoint this scenario should not be considered as an interim case towards unleaded gasoline.

Table 2: Results for ERGA and CONCAWE Scenarios

Scenarios: ERGA	Base	I	II	III	IV	V		
Additional							A	B
Lead g/l max.	0.4	0.15	NIL	NIL	NIL	NIL	NIL	NIL
RON min.	98/92	98/92	92	94	96	98/92	96/92	94.5
MON min.	88/82	88/82	82	84	86	88/82	86/82	84.5
% of gasoline pool:			100	100	100			100
Premium grade	75	75					75	
Regular grade	25	25					25	
Δ Energy (a) t/1 000 t	0	+22	+56.8	+44.8	+53.0		+44.8	+44.3
Δ Cost (b) x10^3$/1 000 t	0	+12.1	+19.7	+18.9	+24.5		+20.3	+19.3
Δ Investment (c) x10^3$/1 000 t	0	14-29	17-26	24-38	33-57		26-45	25-39
<u>Quality change of pool</u>								
Δ Aromatics, % vol.	0	+ 3	+ 6	+ 7	+10		+ 9	+ 8
Δ Benzene, % vol.	0	+ 0.1	+ 0.4	+ 0.7	+ 1.0		+ 0.8	+ 0.7

(a) t crude per 1 000 t gasoline in base case.

(b) US$ (1983) x 10^3 per 1 000 t gasoline in base case. Includes capital charge, crude oil and operating costs.

(c) US$ (1983) x 10^3 per 1 000 t of annual gasoline production in base case.

4. REFERENCE

1. CONCAWE (1980) The rational utilisation of fuels in private transport (RUFIT) - extrapolation to unleaded gasoline case. Rep. 8/80. The Hague: CONCAWE

METHODOLOGY

1. GENERAL APPROACH

The study assesses the impact of lead reduction through the comparison of several scenarios versus a base case (see 2 and 3 below). For all low lead and unleaded scenarios, the differences against the base case for total energy consumption, gasoline costs and investments for additional processes have been calculated. No costs or investments for additional or modified storage and distribution facilities for unleaded gasoline have been included. In addition aromatic and benzene contents of the gasoline pool of each scenario have been calculated.

As with the previous RUFIT study, all calculations have been performed assuming that, regardless of the scenario, motorists will drive the same mileage. For each scenario the quantity of gasoline required to drive this mileage was calculated using three different CEP (Car Efficiency Parameter, defined in 4 below). The output of all other products was kept constant in the calculations.

Differences in total energy requirement, i.e. gasoline consumption by the cars and energy consumption in the refineries have been expressed in equivalent tonnes of Arabian Light crude oil, for an output of 1 000 tonnes of gasoline in the Base Case.

Investments and costs were calculated in terms of 1983 US dollars. Since there is a general trend in Europe towards increased conversion, the calculations have been carried out using three different computer models representing future European conversion refineries. The study covers only the ultimate situation, 10-15 years after introduction of unleaded gasoline, without consideration to intermediate situations. It was also assumed that the facilities used in the refineries are representative of the most modern technology.

In the unleaded case optimum octane numbers have been calculated both for energy consumption and cost. It must be stressed that these optima are the octane values at the refinery.

2. Base case

All details regarding the base case and the alternative scenarios have been discussed with, and agreed by, the ERGA II Group.

The base case considers a dual grade system defined as follows:

	Regular	Premium
RON	92	98
MON	82	88
Ratio (%)	25	75
Lead content (gPb/l)	0.4	
Δ RON, 100°C Distillate	max. 12	
Specific gravity	max. 0.78	
Vapour pressure, bar	max. 0.7	
Volatility:		
Evaporated at 100°C (vol %)	50-65	
Final boiling point (°C)	max. 210	
Aromatics (vol %)	to be reported	
Benzene (vol %)	to be reported	

This represents a leaded pool octane (see Appendix IV) of 96.5 RON/86.5 MON

Except for lead content, RON and MON, the same definitions are valid for all other scenarios.

The following product slate is used in the base case:

Gasoline	25 wt%
Middles distillates	41 wt%
Heavy fuel oil	21 wt%
Other products	13 wt%
Total	100 wt%

Expressed as a percentage of crude oil processed, these figures will vary in the different scenarios depending on the amount of gasoline relative to the other products and depending on refinery energy consumption (The tonnages of all products except gasoline remain the same in all scenarios.).

It should be noted that the gasoline characteristics are assumptions for the purpose of this study only and cannot be considered as specifications. Such specifications are set either by National Authorities or as a result of market forces and do not constitute part of this study.

3. Alternative scenarios

The following scenarios are investigated in this study in comparison to the base case:

	0.4 gPb/l		0.15 gPb/l		0.0 gPb/l			
RON/MON	98/88	92/82	98/88	92/82	98/88	96/86	94/84	92/82
Base case	75%	25%						
I			75%	25%				
II								100%
III							100%	
IV						100%		
V					max. poss.			balance
A						75%		25%
B					Optimum Octane Number			

Scenarios I to V are those agreed by the ERGA II Group. Scenarios A and B were added by CONCAWE because they believe that they will provide valuable information.

These scenarios represent a range of alternative situations to enable assessment of feasible solutions and obtain optima for energy and cost in the case of unleaded gasoline.

It should be recognised that for conversion refineries operating at high octane numbers the Motor Octane Number may be the limiting factor and that Sensitivity (i.e. RON-MON) may exceed the value of 10 assumed in the product characteristics. In those cases the calculations aim at meeting the MON as defined by the scenario.

4. ENGINE RESPONSE TO OCTANE - CAR EFFICIENCY PARAMETER

A critical factor in determining the fuel consumption of a gasoline engine is compression ratio: the higher the compression ratio, the lower the fuel consumption. Compression ratio also affects fuel quality requirement of the engine: the higher the compression ratio, the higher the octane number required for the gasoline. Consequently there is a relation through compression ratio, between fuel economy and the octane quality of available gasoline. The engine fuel consumption will increase as compression ratio and the octane quality decrease.

The Car Efficiency Parameter - CEP is used to describe the increase of engine fuel consumption in weight percent per unit decrease of octane number. In connection with the original RUFIT study, the European car industry, represented by CCMC, measured the CEP of a number of engine models under strictly comparable conditions of performance and emission control. A value of 1.0 % wt of gasoline/RON was shown to best reflect the average engine response to octane numbers.

No such systematic investigation has been performed since and, therefore, no specific data are available for modern, more fuel-efficient engines meeting advanced levels of emission control.

Consequently on the advice of the ERGA II Group CONCAWE used a CEP of 1% wt/RON for the whole of the investigations. However, as CEP is a vital factor in the study, a sensitivity study has been carried out by assessing the impact of CEP of 1.5% and 0.5% wt/RON on total energy consumption.

5. REFINERY MODELS

The linear programming models used by the 3 companies reflect the latest refining processes such as low pressure continuous catalytic reforming, hydrocracking and recycle type operations such as catalytic reforming of catalytically cracked naphtha. Product quality, upgrading efficiency, especially with respect to octane numbers, product yields and efficient use of energy in the processes reflect the latest refining technology. The correlation factors used in the computations are proprietary to the respective company and hence are very likely to be different from each other.

In the calculation it was assumed for the base case that the existing refinery facilities were fully utilised.

None of these assumptions reflect the current situation in Europe. However, for a study looking 10-15 years ahead they were felt to be realistic, taking into account both technical developments and the continuing rationalisation of the refining industry in Europe.

The assumed size of the refineries is about 5 x 10^6 tonnes of crude oil per year. For linear programming this assumption is uncritical. It was left to the respective computer model to define the refinery configuration for each scenario by minimising cost and energy usage. However, in order to reflect practical conditions, some constraints have been taken into account, e.g. it was assumed that the refining facilities of the base case were also available in the various scenarios and the model had to fully use the base case conversion capacities, thus reflecting the trend towards increasing conversion.

Furthermore, the size of any new facilities has been controlled so that the models constituted realistic cases and did not contain unrealistically small process units. Finally, as requested by the ERGA Group, the models did not utilise modern, investment-intensive processes such as Flexicoking, which are not expected to be utilised in large numbers in Europe until the end of this century.

Crude slates consisted of a mix of low sulphur crude oil (North Sea, Nigeria etc.) and medium sulphur crude oils (Persian Gulf). The product output was kept constant at the level assumed in the base case with the exception of motor gasoline. Therefore, the changes in the crude requirement directly reflect the change in motor gasoline product demand and quality. Any incremental crude required to meet the necessary output was introduced as Arabian Light crude (at 1983 price 29 $/barrel = 220 $/tonne).

Computer models were allowed to utilise additional processing facilities, if required, to meet the specified product demand (both quantitatively and qualitatively). An annual charge of 25% of capital cost was specified for any new process plant taken up in the calculation. All costs and investments were calculated in terms of 1983 US dollars.

Further, it should be noted that each model represents a specific set of circumstances and that the changes in processing severity/complexity were left to the discretion of the computer model concerned. Consequently, the reported results represent a range of circumstances and indicate that some refineries will be better placed than others to make the necessary changes.

The conclusions drawn from this study represent consolidated averages of the 3 computer models. In order to verify the validity of the results, computer models of 6 more companies participating in CONCAWE have been used to calculate energy differentials for one specific scenario against the base case.

RESULTS OF COMPUTATIONS

1 Processes

Out of the extensive list of processes available in the various computer models, the following processes which are relevant for gasoline quality and yields have been used in the computations:

Catalytic Cracking	
Catalytic Reforming	- conventional high pressure reforming - low pressure continuous catalytic reforming - reforming heart cuts of cat. cracked naphtha
Hydrogenation	
Alkylation	
Isomerisation	- C_5/C_6 isomerisation - total isomerisation - once through and recycle isomerisation
Iso-pentane Splitting	
Visbreaking	
Coking	
Hydrocracking	

2. Energy Consumption - Unleaded Cases

Figure 3 shows the results for energy consumption for a CEP = 1.0 of the three individual computer models and the average calculated from the results. The different levels of energy consumption in the individual submissions reflect the range of processes used in the base case, the different types of upgrading processes used in the individual scenarios, and the differences in energy consumption for the various processes assumed in the individual computer models. The additional points shown at 94 RON/84 MON represent the results of checks performed by 6 other participants using their proprietary computer models. These check points are a good confirmation for the validity of the three individual curves and clearly confirm that the average curve is representative for the future European refining industry. The differences in energy consumption therefore are representative of the variation which can be expected in practice.

Inspite of the differences in energy usage of the three individual submissions it is notable that all models show the minimum for total energy usage, that is the optimum octane number, within a range of less than one octane number, the average being 94.5 RON/ 84.5 MON.

It is even more notable that all three models show that above 86 MON it rapidly becomes technically infeasible to manufacture gasoline in the quantities necessary to meet the market demand. This clearly shows the limits of currently available and foreseen technology for producing high octane numbers.

In this context, it is important to understand that it is not always possible to maintain a sensitivity (RON-MON) of 10 so that, especially at high octane levels there may be RON "give-away", i.e. at high octane levels MON becomes the limiting factor for most refineries.

As far as the scenarios asking for a dual grade gasoline system are concerned, the following results have been obtained:

a) Scenario V: (98 RON/88 MON premium grade at the maximum possible ratio, balanced by a 92 RON/82 MON regular grade).

One model indicated that maximum 30% of the premium grade could be manufactured, the other two models showed availability below this value. In all three cases the composition of the premium grade with respect to the components utilized was very unconventional although all defined quality characteristics had been met according to the data available in the computer programmes. However, because of the unconventional nature of this premium grade all participating companies stressed the point that the blending correlations used in their models had not been verified for such a case and could, therefore, be considerably less accurate than for the other cases. As it was not possible to arrive at a common number for the maximum availability of the 98 RON/88 MON premium grade it was not possible to calculate a meaningful figure for the related energy consumption or for any of the other criteria, such as cost, investment, aromatic content.

Attention is drawn to the fact that because of these technological limits the maximum availability of a 98 RON/88 MON premium will be, on average, less than 30% and that many refineries will not be able to manufacture such a grade in any sizeable quantities even after investments for octane upgrading processes. Therefore, general availability of this grade cannot be assumed.

b) Scenario A: (96 RON/86 MON premium grade at 75%,
92 RON/82 MON regular grade at 25%).

The average Δ crude oil/1 000 tonnes of gasoline for this case is 45 tonnes. This is similar to the energy differential of the 94 RON/84 MON single grade case of Scenario III. However, it must be realised that significantly different process equipment may be required for the dual grade case because of the need to manufacture high octane components for the premium grade.

3. Cost and investment - Unleaded cases

Figure 4 shows the average of differences in cost for the unleaded gasolines of varying octane number versus 1 000 tonnes of gasoline in the Base Case, together with the range of the individual submissions for a CEP = 1.0. The curve shows a minimum, that is an optimum octane number for cost, at about one octane number below the optimum for energy. It must be understood that these costs reflect only the changes occurring within refineries and the changes in fuel consumption of cars. It does not include cost changes for storage and distribution of unleaded gasoline which can be substantial, especially during the transition period.

An important element of the cost shown in Figure 4 is the capital charge for additional refinery investment for the different cases. These investments had the following ranges:

	RON/MON	92/82	94/84	96/86
Δ Investment vs base case 10^3\$/1 000 t gasoline		17-26	24-38	33-57

To correctly understand the significance of these numbers it must be remembered that an essential assumption of the study is the full utilisation of the refinery in the base case. Therefore the above investments represent significantly different types of equipment in the various cases. At lower octane numbers fuel consumption of the cars is higher and, therefore, investment is necessary to produce additional quantities of gasoline. At higher octane numbers, investments are necessary to increase the octane number above that of the unleaded pool in the base case and in these cases investment increasingly represents additional octane upgrading equipment.

At present there is considerable excess refinery capacity in Europe. To what extent this excess capacity will still be available at the time assumed in this study, i.e. 10-15 years after the introduction of unleaded gasoline, is very uncertain, but it will be considerably less than today. The existence of excess capacity would certainly reduce or eliminate the need for investments for additional quantities of gasoline. On the other hand, the need to invest for additional octane upgrading facilities is less influenced by excess capacity as this often requires types of equipment which are not found in many of the existing refineries. In this context it is important to realise that even for the base case this study assumes a refinery optimised for cost and energy consumption which is not the case for many existing refineries. As a result investments required in refineries may differ more widely than the range indicated by the three computer models.

As for the two grade gasoline cases no meaningful cost and investment figures are available for Scenario V as explained in Section 2a of this appendix. For Scenario A (96 RON/86 MON - 75% - 92 RON/82 MON at 25%) average Δ cost per 1 000 tonnes of gasoline amounts to 20 x 10^3 $, the investments range from 26 to 45 x 10^3 $ per 1 000 tonnes of annual gasoline production in the base case.

4. Aromatics and benzene content - unleaded cases

On the basis of the data available for the various blending components, both the aromatics content and the benzene content of the gasoline pool have been calculated as follows:

Scenario	Base case	I	II	III	IV	A	B
RON/MON	98/88(P) 92/82(R) 0.4gPb/1	98/88(P) 92/82(R) 0.15gPb/1	92/82	94/84	96/86	96/86(P) 92/82(R)	94.5/84.5
Aromatics (vol%)	31-37	34-39	36-40	36-43	36-45	36-44	36-43
Benzene (vol%)	2.4-2.8	2.5-2.8	2.5-3.0	2.8-3.6	3.2-3.6	2.9-3.5	2.8-3.6

(P) = Premium Grade (R) = Regular Grade

The ranges indicated for Aromatics and Benzene content are those indicated by the three models. The average values used for calculating the differences listed in Table 2 are not necessarily the midway point of the range.

As previously stated, no meaningful data can be provided for Scenario V. Directionally, however, the aromatics and benzene contents will be the highest of all cases. The aromatics content of the premium grade in Scenario A will range from 44 to 52 vol. % and the benzene content up to 4% vol.

In view of the considerable catalytic cracking capacities assumed in the Base Case, both aromatics content and benzene content in these model calculations will tend to be on the low side. Refineries operating with smaller cat. cracking capacity and hydroskimming refineries may produce somewhat higher aromatics contents and considerably higher benzene contents.

The significant changes in gasoline composition when moving to unleaded gasoline, especially at higher octane levels, may not be without influence on other factors particularly on automotive exhaust gas composition. This is particularly important for certain hitherto unregulated emittants which are currently under discussion in several countries namely benzene and polycyclic aromatics.

In a separate paper, CONCAWE shows the interdependence between gasoline composition, emission control and benzene emissions. In view of this and other suspected influences of gasoline composition on raw exhaust gases it may be prudent to combine moves to unleaded gasoline with appropriate emission controls which is, anyway, a major driving force for the elimination of lead in some countries.

5. Influence of CEP on optimum octane number

Figure 2 shows the results of the computations for different CEPs on total energy consumption. In comparison to the CEP of 1.0 a reduction of CEP to 0.5 reduces the optimum octane number by 1.5 units and also reduces the extra energy required in comparison to the base case. On the other hand, an increase of CEP to 1.5 increases the optimum octane number by one unit close to the technically feasible limit and in addition, considerably increases the energy penalty vs the base case. These data stress not only the importance of knowing the CEP of future cars but show also the incentives in energy terms to reduce CEP. Optimum octane number for cost and cost differentials will be influenced by CEP in the same way as energy.

6. Scenario I - Two grades at 0.15 gPb/l

Scenario I - assumes the same octane numbers and grade split as the Base Case but at a maximum lead content of 0.15 g/l gasoline. The increase in crude/1 000 tonnes of gasoline is 22 tonnes. The additional investment ranges between 14 - 29 x 10^3\$/1 000 tonnes of gasoline and the corresponding increase in cost 12 x 10^3\$/1 000 tonnes of gasoline. All investments in this case are for octane upgrading facilities as there will be no change in gasoline consumption. It must be realised that the type of investment required in this case is not necessarily the same as for the unleaded cases.

THE ROLE OF OXYGENATES WITH LEAD REDUCTION

A number of unconventional materials are now being considered as gasoline blending components. These are oxygenated compounds, namely alcohols such as methanol, ethanol and tertiary butanol (TBA) and ethers such as methyl-tertiary-butyl ether (MTBE). For this study, the possible use of oxygenates to compensate for a reduction in lead has to be considered on an overall EEC basis rather than for a single refinery. Consequently, two aspects have to be looked at:

- octane boost compared to lead reduction
- availability

In Europe, the oxygenates of particular interest are methanol, TBA and MTBE. The typical blending octane numbers (BRON/BMON) of these components in a gasoline produced in a conversion refinery are:

	BRON	BMON
Methanol	130	100
TBA	105	90
MTBE	110	100

It should be noted that a wide range of blending octane numbers are reported in the literature and that blending octane numbers do vary with octane number and composition of the base gasoline. The above values are approximate and refer to a base premium gasoline without lead.

A first approach is to use these blending values to calculate the volume of oxygenate required to replace lead. Consider a premium grade gasoline of 98 RON/88 MON with 0.15 gPb/l. The lead can be taken as adding 3 ON and consequently the base gasoline is 95 RON/ 85 MON. For the oxygenates, it is MON which is the critical factor and therefore the percent volume of oxygenate required to raise MON back to 88 has been calculated.

	Percent Volume
Methanol	20%
TBA	60%
MTBE	20%

This is very much a best case since other gasoline properties such as volatility have not been taken into account which would have to be significantly modified to compensate for these high concentrations of oxygenates.

However, as shown by the draft EEC directive (1) the concentration of the various oxygenates in gasoline must be limited to ensure satisfactory performance of vehicles. The proposed limit is 10% vol total oxygenates with methanol further limited to 3% vol maximum and used with a co-solvent. It is obvious from this simple analysis that it is not possible to simply replace lead by oxygenates, even in moving from 0.15 gPb/l to 0.

At the limits set by the proposed directive, a small compensation for lead reduction could be achieved, but the second factor to look at is availability compared to the EEC gasoline demand. Estimates were made for the availability of these oxygenates for gasoline blending in Europe in 1990 (2).

	Estimated availability 1990 x 10^3 tonnes
Methanol	1 500 - 3 000
TBA	400 - 600
MTBE	600 - 800

These figures, which are considered optimistic, have to be compared to the EEC gasoline demand of about 80 million tonnes. Only methanol may be available in sufficient quantities to be widely used. However, to ensure a stable mixture, a co-solvent has to be used with the methanol to inhibit separation in the presence of water. TBA is the commonly used co-solvent and, as can be seen, will only be available in very limited quantities; consequently methanol use would be limited by co-solvent availability.

It is clear from the availability estimates that oxygenates cannot play a major role in the context of the overall EEC demand and for these reasons have not been taken into account in the refinery calculations.

However, some refineries will use oxygenates, depending on individual circumstances and economics, and a reduction of lead in gasoline is likely to result in an increase in their use over the present day.

REFERENCES

1. EEC (1982) Proposal for a Council Directive on crude oil saving through the use of substitute fuel components in petrol. Official Journal C 229

2. Chem Systems International (1982) Study on the possibilities for the replacement of lead in gasoline by the addition of compounds. (prepared for EEC Commission, contract number AS/81/222) Final report. London: Chem Systems International

POOL OCTANE NUMBER AND GRADES OF GASOLINE

The original RUFIT study assumed a single grade of gasoline and a car population matching the octane level of this gasoline. The octane number of this single grade, therefore, is identical with that of the pool in a given refinery manufacturing the gasoline. This is referred to as the pool octane number. It is important to understand that gasoline is a blend of various refinery streams and not a product from a single process.

However, most suppliers of gasoline in Europe offer at least two grades of gasoline, normally referred to as the regular grade and the premium grade. These grades match the octane requirements of two distinctly different car populations which have been specifically designed for the use of either regular grade gasoline or premium grade gasoline. It is possible to calculate from the components going into the pool splits into various multi-grade systems both with respect to octane levels and to quantities, although such calculations are complex. Because of the complexity of gasoline blending, it is not possible to use a simple approach by considering only the Research Octane Number and assuming linear blending behaviour. For example, a gasoline pool of 94 RON cannot be split into equal volumes of two grades, having 92 RON and 96 RON respectively, without due consideration of other factors. Each case has to be calculated separately since linear blending of RON is only approximate and other characteristics such as MON and volatility are important. Because of lack of components with sufficiently high octane numbers it will not always be possible to manufacture the higher octane number grade. These additional factors tend to limit the available quantities of the high octane grade.

On the other hand, the calculation of the octane number of a refinery pool from actual quantities and octane numbers of different gasoline grades is straightforward. In that case, each of the grades has all desired properties and are full boiling gasolines (as compared to narrow boiling components), and linear blending characteristics can be safely assumed. Thus, equal quantities of a regular grade gasoline of 92 RON - 82 MON and a premium grade gasoline of 96 RON - 86 MON result in a pool of 94 RON : 84 MON.

Pool octane numbers can be calculated for both leaded and unleaded cases. For the unleaded case, it is usual to refer to the clear (= unleaded) octane pool.

For correctly designing engines, car manufacturers need clear information on the number of grades and their respective qualities available at the service stations. However, the car manufacturer will not be able to predict the sales ratio between types of vehicle and thus the share ratio between the two grades will depend entirely on the buying habits of the customers who are influenced by pricing policies of both the car and the petroleum companies, perceived fuel consumption and/or performance advantages etc. The current diversity in Europe, e.g. 55/45 premium/regular share in Germany, 95/5 premium/regular share in Italy, demonstrates this point.

To asses the impact on energy usage, cost and investment in the refineries, the petroleum industry needs to know both the quality and volumes of the different grades. Therefore, for a rational approach to the introduction of several grades of unleaded motor gasoline, industry needs to make assumptions about the premium/regular share. However, the actual buying behaviour of customers could be quite different.

COMPARISON OF THE SITUATION IN THE USA AND JAPAN WITH EUROPE

1. USA

Unleaded gasoline was introduced in the USA during 1974 in order to provide a suitable fuel for the catalyst-equipped cars which had to be introduced from model year 1975 onwards. The initial octane quality of the unleaded fuel was min. 91 RON, as agreed between Administration, car industry and petroleum industry. Somewhat later, it became customary in the USA to define octane quality by the term:

$$\frac{\text{Research Octane Number plus Motor Octane Number}}{2} \text{ or } \frac{R + M}{2}$$

This is currently min. 87 for the regular unleaded grade, typically corresponding to a MON of min. 82 and RON of min. 92.

As a result of the pressure on US motor manufacturers to improve the fuel economy of their cars, they tended to increase the compression ratio and thereby octane requirement, especially of their larger models. In response, the petroleum industry tended to delete the leaded premium grade, the demand for which had dropped significantly in the meantime, and to replace it by an unleaded premium grade of (R + M)/2 of min. 91; typically a MON of min. 86 and a RON of min. 96. Although this unleaded premium grade accounts for about 15% of all gasoline sales it is still not available everywhere in the USA. Mid 1983 the situation in the USA was as follows:

	min. $\frac{R + M}{2}$	min. RON	min. MON	Share, %
Leaded regular	89	93	85	40
Unleaded regular	87	92	82	45
Unleaded premium	91	96	86	15

NB. Leaded premium is now available only to a very limited extent (less than 1%).

This results in a clear (unleaded) total pool of about 90.5 RON, 81 MON. There are two further important differences between the USA and Europe:

- the still large amount of leaded regular gasoline, mainly used for gasoline engine powered trucks, offers a large outlet for low octane components. This outlet does not exist in Europe

- in the USA the share of gasoline amounts to 42% of total crude oil consumption as compared to the current 18% in Europe and 25% assumed in this study. This high degree of conversion provides a considerable amount of feedstocks for high volatility/high octane components, e.g. alkylates and isomerates.

2. JAPAN

Japan moved to unleaded gasoline in 1975 by introducing an unleaded regular grade gasoline of 91 RON. Today, this grade is almost 97% of all gasoline sold. Some companies very recently started to offer an unleaded premium grade of 98 RON/86 MON. The current share of this grade, which is not yet generally available in Japan, is less than 2%. It is not expected to grow beyond 10%.

GLOSSARY

The following simple explanations of terms used in this report are provided for those readers not acquainted with technologies for the manufacture of gasoline or its use in vehicles.

With respect to the refining processes mentioned, it is important to understand that the use of some of them is dependent on the presence, in the same refinery, of other processes which provide the essential feedstocks for them. In some cases, the capacity of the unit providing the feedstock is determined by its primary purpose, e.g. cat. cracking, cat. reforming, and not specifically to provide those particular feedstocks. Thus, certain processes cannot be used in all refineries and their capacity may be limited by feedstock availability.

Gasoline Characteristics

OCTANE NUMBER

The octane number of a fuel is a number equal to the percentage by volume of iso-octane in a mixture of iso-octane and normal heptane having the same resistance to detonation as the fuel under consideration in a special test engine. It is a measure of the anti-knock value of a gasoline and, in the case of the special test engine, the higher the octane number the higher the anti-knock quality of the gasoline.

RESEARCH OCTANE NUMBER (RON)

The octane number of a motor gasoline determined in a special laboratory test engine, under mild "engine severity" conditions, giving a rough measure of the low-speed knock properties of the gasoline.

MOTOR OCTANE NUMBER (MON)

The Octane Number of a Motor Gasoline determined in a special laboratory test engine under high "engine-severity" conditions, giving a rough measure of the high-speed knock properties of the gasoline.

SENSITIVITY

The sensitivity of a gasoline is the difference between the RON and the MON. Depending on the hydrocarbon composition of the gasoline, sensitivity can range up to 15.ON but is normally in the range 8 to 12.ON.

ROAD OCTANE NUMBER

The Octane Number of a motor gasoline determined during actual road testing. Apart from the intrinsic quality of the gasoline tested, the Road Octane Number depends also on the make of the engine of the vehicle and reflects the severity of the engine/vehicle combination. In general the Road Octane Number lies between the RON and MON of the gasoline.

FRONT END OCTANE NUMBER

The Research ON of the gasoline fraction boiling up to 100°C. This is important with respect to low speed acceleration knock in European cars.

OCTANE REQUIREMENT

The octane quality of gasoline necessary to ensure knock-free operation in a given vehicle under road driving conditions. Determined by standardized test methods.

OCTANE REQUIREMENT INCREASE

The increase in vehicle octane requirement with accumulated mileage. Increases are caused by the accumulation of deposits in the combustion chambers.

VOLATILITY

The ability of a gasoline to evaporate. This characteristic is important for engine operation with respect to starting, warm-up under cold ambient conditions and vapour lock during warm ambient conditions.

REID VAPOUR PRESSURE (RVP)

The pressure caused by the vaporized part of a liquid and the enclosed air and water vapour, as measured under standardized conditions in standardized apparatus: the result is given in millibars at 38°C. There is no simple relation between the RVP and the true vapour pressure of the liquid. RVP gives some indication of the volatility of a liquid, e.g. gasoline.

The RVP of gasolines is adjusted seasonaly throughout Europe to compensate for changes in summer or winter conditions.

REFINING PROCESSES

DISTILLATION (fractional)

A fractionation process based on the difference in boiling point of the various constituents of the mixture to be fractionated. It is carried out by evaporation and condensation in contact with reflux. When applied to the separation of gasoline, kerosine, etc., from a crude oil, to leave a residual fuel oil or asphaltic bitumen, the process is frequently called topping. Distillation is normally carried out in such a way as to avoid decomposition (cracking); in the case of the higher boiling distillates, such as lubricating oils, this is accomplished by carrying out the distillation under vacuum.

ATMOSPHERIC (PRIMARY) DISTILLATION

The basic process in oil refining which makes the initial separation of crude oil into broad fractions, e.g. gases, gasoline, kerosene, middle distillates, leaving a "long" residue of high boiling point material.

The capacity of atmospheric distillation units must be sufficient for the total amount of crude oil necessary to produce the full range/volume of products to be produced and also the refinery's own energy requirements.

VACUUM DISTILLATION

Distillation of a liquid under reduced pressure, aimed at keeping the temperature level so low as to prevent appreciable cracking. For example used to distill gas oil, lubricating oils or catalytic cracking feedstock from residue, leaving a "short" residue as remainder.

CRACKING

Process whereby the large molecules of the heavier oils are converted into smaller molecules of the gasoline type. When this is brought about by heat alone, the process is known as thermal cracking. If a catalyst is also used the process is referred to as catalytic cracking, or as hydrocracking if the process is conducted over special catalysts in a hydrogen atmosphere.

CATALYTIC CRACKING

Process of breaking down the larger molecules of heavy oils into smaller ones by the action of heat, with the aid of a catalyst. In this way heavy oils can be converted into lighter and more valuable products (in speech generally abbreviated to cat. cracking).

THERMAL CRACKING

Process of breaking down the larger molecules of heavy oils into smaller ones by the action of heat. In this way heavy oils can be converted into lighter and more valuable products.

HYDROCRACKING

A process used to convert heavier materials into light fractions boiling in the gasoline/middle distillate range. It combines cracking with hydrogenation. Additional hydrogen production facilities may be required if insufficient hydrogen is available from the catalytic reforming capacity available in the refinery.

VISBREAKING

A process to upgrade atmospheric or vacuum residues by thermal conversion into primary middle distillates, leaving a residue (fuel oil) with improved quality.

PYROLYSIS

A severe form of thermal cracking.

PYROLYSIS GASOLINE

A by-product of high-temperature (700 - 900°C) thermal cracking processes aiming primarily at ethylene manufacture. Because of its high benzene content, it is usually subjected to an extraction process to recover the benzene for use in the chemical industry. The pyrolysis gasoline may be blended into gasolines at a small number of refineries. Additional extraction may be required if low benzene content limits are applied to the finished gasoline.

REFORMING

The operation of modifying the structure of the molecules of straight run gasoline fractions under strictly controlled conditions in order to improve ignition quality. It can be achieved thermally (thermal reforming) or with the aid of a catalyst (catalytic reforming).

CATALYTIC REFORMING

Process for changing the molecular structure (e.g. naphthenes into aromatics) of the components of straight-run gasoline or of a gasoline fraction by subjecting the gasoline to thermal treatment in the presence of a catalyst (for example platinum). By this process the anti-knock performance of the gasoline is improved. The reforming process produces limited quantities of hydrogen as a byproduct which can be used for other refining processes.

HIGH PRESSURE CATALYTIC REFORMING

The high pressure necessary to inhibit unwanted hydrocracking limits the severity of the reforming reaction so that the RON of the products is limited to 98/99 maximum.

LOW PRESSURE-CONTINUOUS CATALYST REGENERATION REFORMING

Latest developments in reforming processes/catalysts permit lower pressures and higher reforming severities than in conventional high pressure reforming processes, reaching levels of 102 RON. This normally requires the continuous regeneration of the catalyst to maintain process efficiency.

This type of processing is installed to only a limited extent at present.

CATALYTICALLY CRACKED NAPHTHA REFORMING

Cat. cracked naphtha has an MON of less than 80. This material is not suitable for direct processing in cat. reformers due to its deleterious effect on catalyst life. "Heart cuts" of the cat. cracked naphtha boiling in the range 90-150°C may be seperated, hydrogenated (hydro treating) to reduce the degree of unsaturation, and mixed in limited quantities with conventional reformer feedstocks. The MON of the reformed cat. cracked naphtha is increased to about 88.

It should be noted that many of the hydrotreating units currently installed are not capable of achieving the level of hydrogenation required, and that the limited availability of hydrogen from the catalytic reformers may require the installation of additional units for the production of hydrogen.

ISOMERISATION

A process for upgrading the anti-knock quality of the C_4/C_5 fractions of a gasoline blend. Isomerisation of these fractions raises their RON by about 20 units to 89 - 90 RON, improving the front end ON of the finished unleaded gasoline.

ALKYLATION

A process combining iso-butane with olefinic gases from cracking processes to produce a liquid hydrocarbon with anti-knock qualities of about 92-94 RON.

The extent to which this process can be used in a given refinery is limited by the availability of the feedstocks, particularly olefins, and possible competition from more economically favourable end uses for them.

Fig. 1 Optimum crude use and cost - Unleaded Gasoline

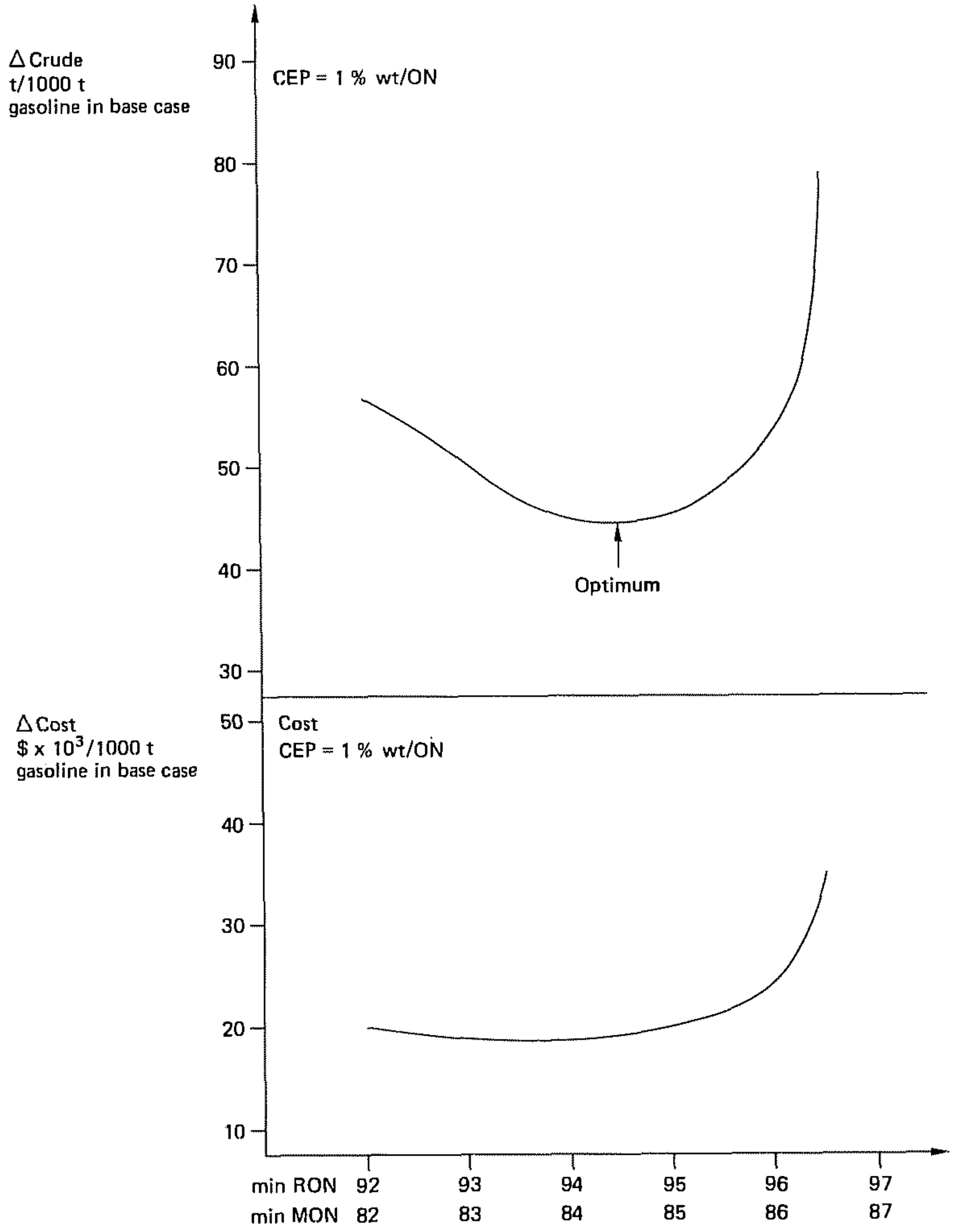


Fig. 2 Optimum energy use: effect of CEP - Unleaded Gasoline

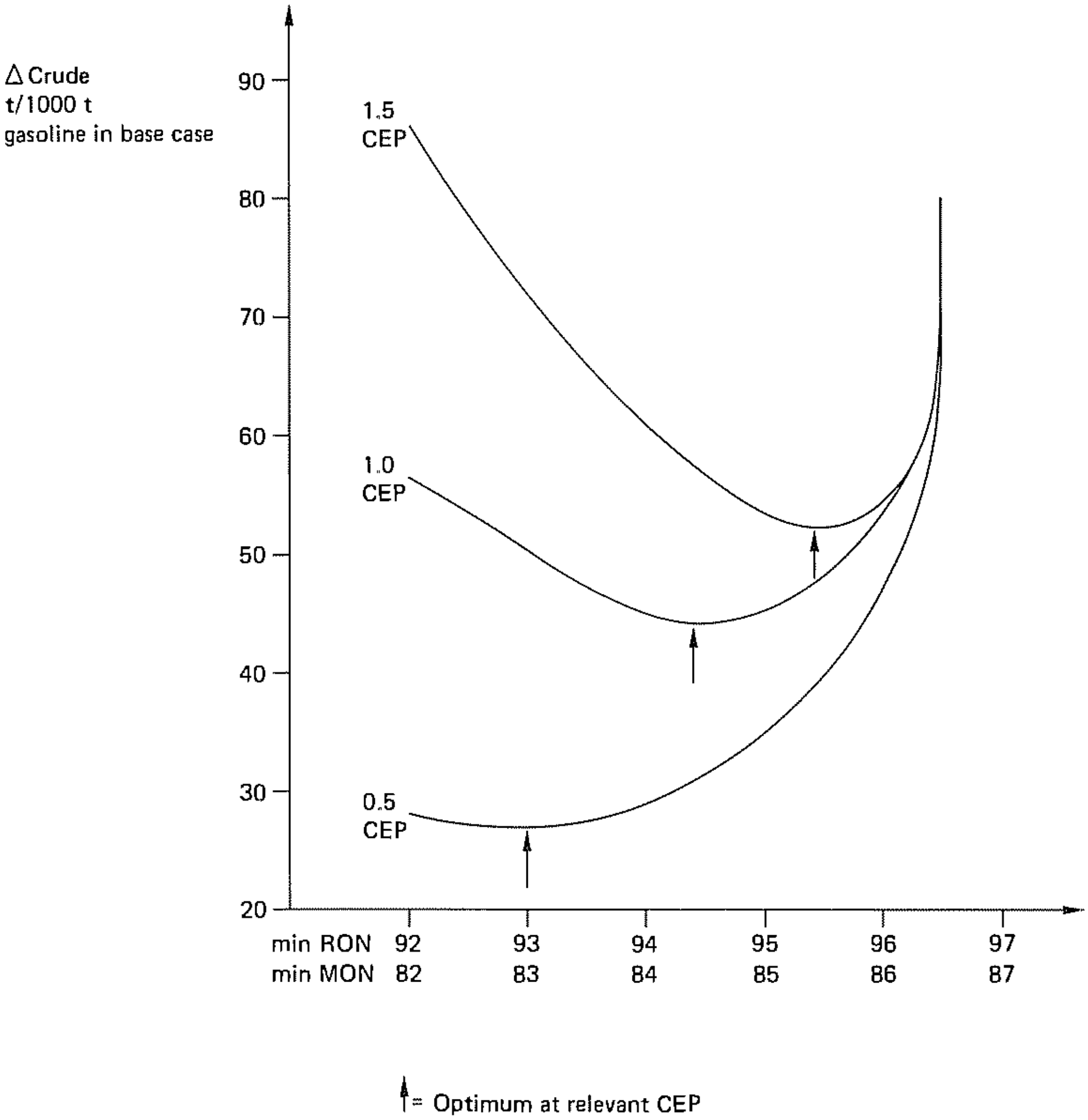
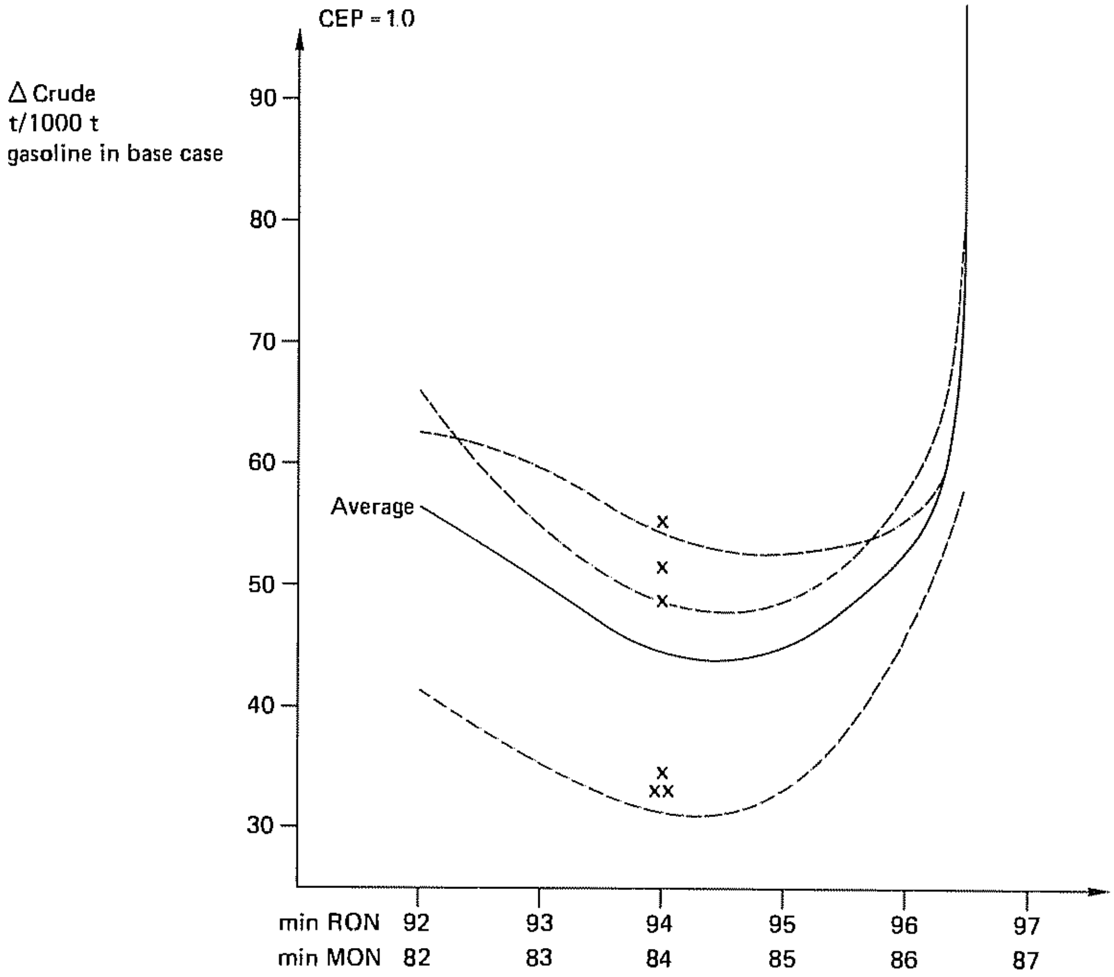


Fig. 3 Optimum energy use: individual submissions-Unleaded Gasoline

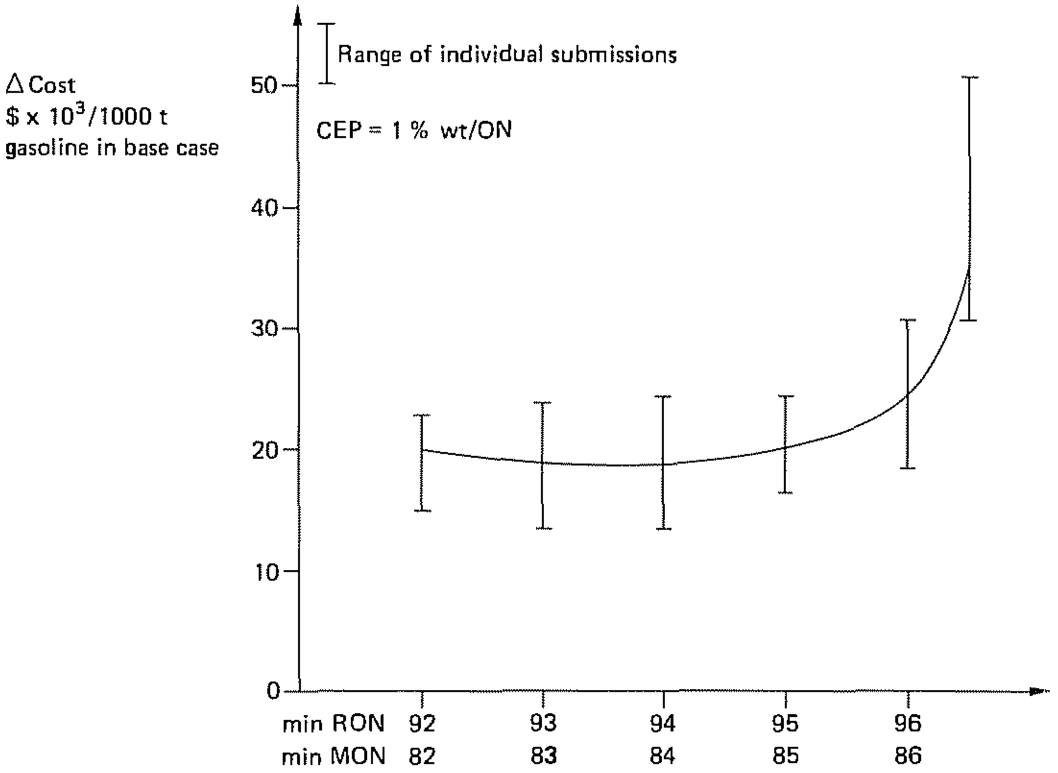


--- Curves of individual submissions

— Average of 3 submissions

x 6 Individual checkpoints

Fig. 4 **Cost: average of 3 submissions**



Cost = Annual capital charge + operating costs + crude cost − lead cost saving

Fig. 5 Refinery investment: average of 3 submissions