concawe

report no. 6/87

volatile organic compound emissions in western europe: control options and their cost-effectiveness for gasoline vehicles, distribution and refining

Prepared for the joint Automotive Emissions and Air Quality Management Groups of CONCAWE based on published CONCAWE reports.

The Hague
September 1987

ABSTRACT

This report summarises the conclusions drawn by CONCAWE from its recent work on volatile organic compound (VOC) emissions in Western Europe. The underlying data are published by CONCAWE; VOC emissions inventories are addressed in Reports Nos. 2/86 and 87/60, car evaporative emissions in Report No. 87/60, and oil refinery and gasoline distribution system emissions in Reports Nos. 87/52 and 85/54. The conclusions presented herein include technical and cost-effectiveness information to help in selecting measures and assigning priorities in the development of any regulations felt to be necessary to limit VOC emissions. Emphasis is given to the largest significant sources, and the report therefore concentrates more on emissions from cars and to a lesser extent on refineries and gasoline distribution systems.

CONTENTS

SUMMARY

In view of the growing interest in Europe in emissions of volatile organic compounds (VOC) which include hydrocarbons, CONCAWE has completed a number of technical studies on the subject.

These studies cover emission inventories, assessment of available control technologies for motor gasoline use and oil industry operations and their cost and cost-effectiveness, i.e. cost per tonne of hydrocarbon reduction.

CONCAWE's inventory of all sources of (non-methane) VOC emissions in Western Europe shows that out of a total of 10 million t/yr man-made emissions, mobile sources and solvents account together for 81%, whereas the oil industry accounts for only 6.5%. Natural gas (excluding methane) and a variety of other smaller sources account for the balance. Natural emissions (trees etc.) are about equal to man-made emissions.

With respect to the mobile sources (41% of man-made emissions), the gasoline sector is responsible for 37%. A comparison of controls shows that the greatest emission reduction is obtained by the application of catalysts to vehicle exhaust systems and by enlarged on-board carbon canisters to collect both evaporative and refuelling emissions.

A reduction of gasoline vapour pressure is a less effective control and is more expensive than on-board devices. "Stage 2" control, i.e. service station vapour recovery for refuelling emissions, is the least effective of the controls studied. The combination of reduced gasoline vapour pressure and "Stage 2" controls still recovers less emissions (2.7%) than on-board vehicle canisters (10%) and is significantly less cost-effective.

The equipment to effectively minimise emissions arising from evaporation and combustion of gasolines will create an essentially closed gasoline system. Most importantly, this will enable the gasoline to be geared towards optimum engine performance including fuel economy. Legislation affecting the gasoline specification e.g. in terms of the vapour pressure or the hydrocarbon composition would then be unnecessary.

The solvents sector although identified as a large source of VOC emissions lacks well-documented information on control measures and their costs. Additional efforts in this field are required.

In the Western European oil industry sector, emissions from refineries and distribution sectors represent only some 5% of man-made emissions. These emissions can be reduced by a half by a combination of improved refinery maintenance and inspection measures and of "Stage 1" vapour recovery with a cost-effectiveness comparable to that of on-board canisters for reducing evaporative emissions.

INTRODUCTION

A number of environmental problems have become major issues over recent years. This results from the still-developing scientific understanding of the impacts of pollution on the environment and the resultant perceived need for protective measures. Public awareness is now at a higher level than previously and legislators are moving to improve the situation.

The phenomenon of 'acid rain' is such an issue. At the onset, acid rain was attributed to emissions of sulphur dioxide from the combustion of fossil fuel. Over the last decade the scientific complexity of the transport, transformation and deposition of emissions has been recognised. The concerns have broadened to embrace not only damage to lakes but to soils, vegetation (especially forests) and materials. The original meaning of 'acid rain' has been extended to cover emissions of sulphur dioxide and nitrogen oxides, the strong acids formed by these oxides in the atmosphere, and to ozone. Since volatile organic compounds (VOC) are precursors to ozone formation, emissions of VOC are subject to increasing attention.

Whilst extensive research has led to a scientific acknowledgement of a strengthening causal link between acid rain and lake damage, the scientific understanding of forest damage is still obscure. With damage occurring even in relatively 'clean air' regions it is recognised that the damage is probably the result of various combinations of many factors apart from pollutants. These factors include climate, topography, the nutrient status of soils, disease, species selection, and forest management practices. Among the pollutants, ozone has been identified as a possible important factor in tree damage.

Ozone is produced by photochemical reactions in the atmosphere involving nitrogen oxides. VOC are known to enhance the formation of ozone in conjunction with nitrogen oxides. At present, attention is focussed on the relatively high concentrations of ozone which occur as episodes during the summer throughout Europe. The concern with ozone episodes is not confined to their possible role in forest damage but also to possible adverse effects on vegetation in general, materials, human health, and visibility impairment. Apart from ozone episodes, background levels of ozone are also increasing in Europe. Considerable research is under way to aid the resolution of the ozone issue.

In the absence of adequate scientific understanding of the relationship between emissions and their ultimate contributions to the observed damages, no rigorous criteria exist on which to base emission, air quality or pollutant deposition standards. For this reason, political pressures have led to proposals for arbitrary reductions in emissions of sulphur dioxide and nitrogen oxides. The ozone question and associated VOC emissions are under consideration. To some, these proposals for prompt action are seen to be a necessary insurance against irretrievable damage if action were delayed indefinitely to await a complete scientific understanding.

A number of international organisations in Europe are working on the development of air pollution abatement strategies covering emissions of sulphur dioxide, nitrogen oxides and VOC. Certain countries, with West Germany in the lead and despite the lack of a sound scientific basis, have taken drastic action and are proposing further action to regulate emission limits for these and other pollutants.

CONCAWE strongly supports the view that:

- control policies should be balanced against sound scientific evidence relating cause with effect;

- effective control regulations should begin with the largest significant sources;

- adoption of specific control measures should be preceded by an adequate evaluation of the various technologies available to identify the most cost-effective ones and to recognise those situations where there is still uncertainty on the relationship between cause and effect.

Accordingly CONCAWE has gathered technical and cost information for presentation to interested parties to help in assigning priorities in the development of any regulatory activities felt to be necessary.

With respect to VOC emissions (see Appendix 1 for a more detailed discussion), CONCAWE has recognised that, despite the relatively small contribution to hydrocarbon emissions in Europe arising from petroleum refining and distribution, there is need for documentation on control techniques applicable in these sectors, with an assessment of costs. Gasoline distribution is covered in CONCAWE Report No. 85/54 and oil refining from crude receipt to product dispatch is covered in Report No. 87/52. In these reports data are presented showing emission sources, non-controlled hydrocarbon emissions, control techniques, total investments, annual operating costs and the cost-effectiveness of the controls.

Non-controlled refinery and distribution emissions, in terms of equipment now in use and its state of maintenance, and hence the present efficiency of hydrocarbon retention, vary considerably from place to place depending on local regulations and engineering practice. Partly for this reason, it was decided to base the study on a hypothetical 100,000 barrels/calendar day (5 Mt/yr) refinery (representing about 1% of present refinery throughput in Western Europe) together with its associated distribution and service station facilities for motor gasoline. Emissions from vehicle refuelling at service stations are also considered.

The CONCAWE studies have more recently been extended to examine the impacts, costs and cost-effectiveness of various controls on vehicle refuelling and evaporative emissions. The projected emission reductions have been coupled with emission projections resulting from various vehicle exhaust control regulations to demonstrate the different benefits arising from various combinations of available controls applied to the constantly changing European car population.

The costs quoted in this report, unless otherwise stated, are in terms of 1986 $US i.e.

1 $US = 2.50 Dutch Fl
= 2.20 German DM
= 0.65 UK £

1. VOC EMISSIONS INVENTORY

CONCAWE Reports Nos. 2/86 and 87/60 have provided best estimates of the main anthropogenic sources of (non-methane) VOC emissions from Western Europe. The key elements of that inventory are shown as in Fig. 1. From this it is clear that evaporation of hydrocarbons and oxygenated and chlorinated hydrocarbons during the use of materials such as paints, adhesives, aerosols and plastics, constitute the single largest source of emission of approximately 4 Mt/yr or 40% of the total. Development in vapour recovery systems and the increasing use of alternative non organic based materials could be anticipated to have a significant impact on these sources over the coming years.

The second largest source as shown in Fig. 1 are the emissions from gasoline engined vehicles which include tail pipe emissions (2.5 Mt), running evaporative (1.0 Mt) and refuelling losses (0.18 Mt). These emissions together constitute around 37% of the total of man-made sources.

The remaining contributions as shown in Fig. 1 are made up of a multiplicity of small sources including other transportation around 4%, industrial sources 5.5%, natural gas (non-methane losses) 6.5% and other 2%. Shown separately in Fig. 1 are the combined emissions from oil refining and gasoline distribution which together represent a further 5% contribution.

2. CAR EVAPORATIVE EMISSIONS

The category involves VOC emissions which originate from:

- o vehicle fuel systems so-called running evaporative losses (1.0 million t/yr from gasoline cars)

  - during a period when the vehicle is stationary with the engine hot (hot-soak losses);

  - when being driven (running losses);

  - when standing and subjected to temperature changes (diurnal losses) and from:

- o the displacement of vapours during car refuelling (0.18 million t/yr).

These VOC emissions are negligible for diesel vehicles.

Evaporative emissions can be controlled by three routes:

- the use of on-board canister systems. These are already fitted to automobiles throughout the USA and other parts of the world for the control of vehicle fuel system emissions and by enlarging them, the refuelling losses, although rather small, could be captured as well;

- reduction of gasoline vapour pressure (normally expressed as Reid Vapour Pressure, RVP), affecting both vehicle fuel system and refuelling emissions;

- vapour recovery requiring the transfer of vapour displaced from the vehicle tank to the service station tank during refuelling by using specially designed filling nozzles hoses and lines (so-called "Stage 2" controls).

CONCAWE carried out in 1986 an experimental programme to identify the effectiveness (and relative costs) of the various routes. Tests were conducted using "controlled" (catalytic converters for exhaust emissions and carbon canisters for vehicle fuel system evaporative emissions) vehicles meeting current US emission legislation and "uncontrolled" vehicles, with gasolines of differing RVP. The effect on refuelling losses although not investigated in this programme has been assessed from published CONCAWE and US data.

The conclusions from this study were:

- vehicle and fuel system design has the greatest influence on evaporative emissions from vehicles. Fuel volatility has a significant, but small, effect;

- under standard test conditions (26-30°C) on-board carbon canisters reduce total evaporative emissions by over 90% while a reduction in RVP of 10 kPa would only reduce emissions by 23%. However, under typical ambient temperature in the market and taking account of lower RVP of summer gasolines, an overall reduction of 10 kPa in RVP would give unacceptably low volatility. A smaller reduction in RVP to the 60 kPa level in Summer would only reduce evaporative emissions by 10%. The same reduction would be achieved within two years if new vehicles were fitted with carbon canisters, assuming a new car penetration of 10% per year. Ultimately, of course, canisters would go on to achieve the full reduction of over 90% compared to the much lower reduction achievable with a 60 kPa gasoline.

3. TRENDS ON EXHAUST AND EVAPORATIVE EMISSIONS FROM GASOLINE ENGINED VEHICLES

The data from Report No. 87/60 updated from 2/86 (Appendix 2) shows that the contribution from the gasoline engined car is in three component parts :

	kt	%
Exhaust Emissions	2500	68
Evaporative Emissions	1010	27
Refuelling Losses	180	5
	3690	100

Using the trend modelling approach described in Appendices 2 and 3 CONCAWE has examined the potential impact on total hydrocarbons emissions from the motor car, of control options to limit exhaust emissions, evaporative emissions and refuelling losses from the growing European car population. The basic assumptions used to calculated exhaust emissions are given in Appendix 2. The research work which underpins the assumptions on evaporative losses is reported in CONCAWE Report No. 87/60. The data on "Stage 1" and "Stage 2" derive from CONCAWE Reports Nos. 85/54 and 87/52.

The results of the analysis are shown as in Fig. 2. From 1970 onwards exhaust emission limits for gasoline engined vehicles have been steadily tightened. Comparison of Case 1 and Case 2 highlight the benefits that followed from the progressive implementation of ECE 15, 01, 02, 03, 04 standards (Case 2) versus the "do nothing" Case 1. However, it can be seen that despite this progress, beyond the mid 80's growth in car population exceeds the ability of the ECE 04 regulations to restrict growth in hydrocarbon emissions. It is important to recognise that current EEC legislation only regulates exhaust emissions.

Case 3 indicates that implementation of ECE 05 regulations will prevent any growth in hydrocarbon emissions, but the effect of car population growth, especially in the small car sector (for which 05 improvements on 04 standards are minimal), limits the long term benefits.

Case 4 represents the impact of one of the options identified to control running evaporative and refuelling emissions i.e. RVP control and "Stage 2". The data show the small long term benefit that can be anticipated from Summer period RVP limitations to a ceiling of 60 kPa from 1990 and the "Stage 2" equipment in service stations across Europe during the 1990's.

Case 5 indicates the greater significance of the alternative option i.e. the application of large carbon canisters to all new vehicle registrations in parallel with the ECE 05 exhaust scheme. This derives from the high efficiency that can be realised from canisters in controlling total evaporative losses, which represent the highest recovery target potential (see Section 5).

Case 6, for completeness, highlights the technical capacity that currently exists to reduce hydrocarbon emissions if achievable exhaust emission standards, as applied in the U.S., Japan and Australia, and planned for most of non-EEC Europe, were integrated with the benefit of large carbon canisters.

4. THE ECONOMICS OF ALTERNATIVE EVAPORATIVE LOSS CONTROL

The technical discussion of control options can be most readily translated into economic terms by comparing the two major options available:-

a) the use of RVP control on motor gasoline to control evaporative losses plus "Stage 2" vapour recovery at the Service Station for refuelling loss control and;

b) the use of large carbon canisters "on-board" the vehicle, to control both running evaporative losses and refuelling losses.

The data presented in this and other CONCAWE reports (1,3) have defined the technical basis for this economic assessment. These reports also provide the economic basis for assessing the costs associated with RVP and "Stage 2" controls. The only data available to CONCAWE on the economics of "on-board" controls have been derived from the historic and current discussions which have engaged the U.S. oil and motor industries and environmental control agencies. The uncertainties of those data, when applied to European conditions, are reflected in the wide range of costs that have been cited (5) in this report.

Economic considerations usually defined in terms of cost - effectiveness (i.e. $US/t of hydrocarbon recovered) have also to reflect the potential for recovery that each option offers. These when considered together, provide a measure of the control potential for each of the options available. The data as shown in Fig. 3 indicate that large carbon canisters operating at 90% plus efficiency have the potential to recover just over 1.0 Mt of emissions per annum. The cost-effectiveness is between $US 335/t and $US 1340/t depending on the assumption for the cost of an installed large canister. There is considerable discussion on this cost and CONCAWE has used a range of $US 20 to $US 80 for this study. Even at the high end of the range the data show this approach to offer the greatest and most cost-effective control potential.

The first element of the alternative approach, namely RVP control offers the potential to control only 100 kt of emissions when a downward adjustment in RVP to 60 kPa is applied during the summer period (May - September). The cost-effectiveness, at $US 2100/t, is significantly worse than that of the canister, and the potential for recovery is only 10% of that offered by the canister.

The second element of the alternative approach "Stage 2", vapour recovery at service stations during refuelling of the motor car, has a recovery potential of 160 kt/yr with a capital investment of $US 2-2.5 billion, but the cost-effectiveness is the least satisfactory of all the options at about $US 5000/t.

The combined effect of "Stage 2" plus RVP control offers the potential to recover about 270 kt/yr of emissions, some 27% of the potential offered by the canister. The integrated cost - effectiveness of "Stage 2" plus RVP control is some $US 3850/t. This compares with $US 335-1340/t for the canister.

For completeness the data in Fig. 3 include the cost-effectiveness and recovery potential by "Stage 1" vapour recovery systems to control emissions during the loading of road tankers at oil terminals and refineries, and their discharge at service stations. The recovery potential is 200 kt/yr, the cost-effectiveness is around $US 1100/t. This is comparable to the cost-effectiveness of the canisters on vehicles. The oil industry is already investing in this sector in many countries in Europe, and through the 90's it would be realistic to anticipate that emissions from this source will be progressively recovered to the maximum level (around 90%) that practicable vapour recovery systems will permit.

5. REFINERY EMISSIONS IN PERSPECTIVE

Refinery emissions from crude oil receipt, refining and product dispatch are discussed in CONCAWE Report No. 87/52.

Since emissions from product dispatch, essentially gasoline emissions, have already been covered in the preceeding Section 4, only crude oil receipt and refining emissions are discussed here.

In the case of crude oil receipt, the changeover to segregated ballast with tanker fleet renewal over time (prescribed in the MARPOL 74/78 Convention) will have the complementary effect of virtually eliminating hydrocarbon emissions at crude oil discharge locations by the equivalent of 1.5% of the total 10 million t/yr from man-made sources.

Refinery emissions, based on the study of a hypothetical refinery, represent 1.7% of total emissions. Principal sources considered were:

- process plant fugitive emissions;
- waste water treatment fugitive emissions;
- crude oil and relevant component and product tankage.

Available controls include formal programmes of monitoring and maintenance for process plant fugitives, floating covers for waste water separator bays, and the installation of rim-mounted secondary seals in selected floating roof tanks. These controls could reduce the total emissions of 0.17 million t/yr by 0.07, 0.02 and 0.02 million t/yr respectively at cost of 100, 500 and up to 3,000 $US/t.

6. CONCLUSIONS

Man-made emissions of VOC (excluding methane) in OECD Europe are some 10 million t/yr. The main contributors are mobile sources (41%) and solvents (40%).

Within the mobile source category, the gasoline sector is responsible for 37% of the total man-made emissions. These emissions may be reduced by controls available for vehicle exhausts, evaporative and refuelling emissions.

Gasoline vehicle exhaust emissions, currently represent about 25% of total man-made emissions. Whereas with the ECE 04 regulation, emissions would have reached a virtual plateau, the recently approved ECE 05 regulation will lead to a progressive decrease in emissions up to year 2010. Much more significant reductions would be achieved with the introduction of US-type standards in Europe requiring catalysts not only for large vehicles but also for medium and small engined vehicles which have more than a 90% share of the European car population.

Evaporative and refuelling emissions from gasoline vehicles, representing 10% and 2% respectively of total emissions, could be most cost-effectively reduced by on-board vehicle canisters. The cost assuming a 90% minimum efficiency, would range from about 335 $US/t hydrocarbon removed to 1340 $US/t depending on the canister cost per vehicle. The reduction in emissions would be just over 1 million t/yr.

Alternatively, a reduction in gasoline volatility would cost about 2,100 $US/t hydrocarbon removed but result in a reduction of only 0.1 million t/yr.

"Stage 2" vapour recovery for refuelling emissions would cost some 5,000 $US/t hydrocarbon removed and result in a reduction of 0.16 million t/yr.

In combination a reduction in volatility plus "Stage 2" would cost some 3,850 $US/t hydrocarbon removed for an overall reduction of 0.27 million t/yr. This combined alternative would be very costly compared to the on-board vehicle canister option and the overall reduction would be only a quarter of the canister option.

Operations involving gasoline deliveries by road result in emissions equivalent to 2.2% of total VOC emissions. These emissions may be effectively reduced by 0.2 million t/yr by "Stage 1" vapour recovery at a cost of 1,100 $US/t.

Oil refinery emissions are 0.17 million t/yr and may be reduced by 0.07 million t/yr by formal monitoring and maintenance programmes at a cost of 100 $US/t.

Whilst the EEC regulations have achieved significant reductions in exhaust emissions since 1970, the benefits are now balanced by the growing car population. The new ECE 05 regulation will lead to further reductions up to the year 2010. Additional controls on gasoline volatility and "Stage 2" vapour recovery will enhance the reductions but the alternative on-board vehicle canister will provide four times the reduction in emissions at a much reduced cost. Moreover equipment which minimises emissions by creating an essentially closed system will make it unnecessary to legislate the specification of gasoline e.g. in terms of vapour pressure or hydrocarbon composition. This will enable the gasoline to be geared towards optimum engine performance including fuel economy.

7. REFERENCES

1. CONCAWE (1986) Hydrocarbon emissions from gasoline storage and distribution systems. Report No. 85/54
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2. CONCAWE (1986) Volatile organic compounds emissions: an inventory for Western Europe. Report No. 2/86
   The Hague: CONCAWE

3. CONCAWE (1987) Cost-effectiveness of hydrocarbon emission controls in refineries from crude oil receipt to product dispatch. Report No. 87/52
   The Hague: CONCAWE

4. CONCAWE (1987) An investigation into evaporative hydrocarbon emissions from European vehicles. Report No. 87/60
   The Hague: CONCAWE

5. International Environment Reporter dated 12th August 1987, pages 404/405. Washington DC: The Bureau of National Affairs Inc.

Fig. 1

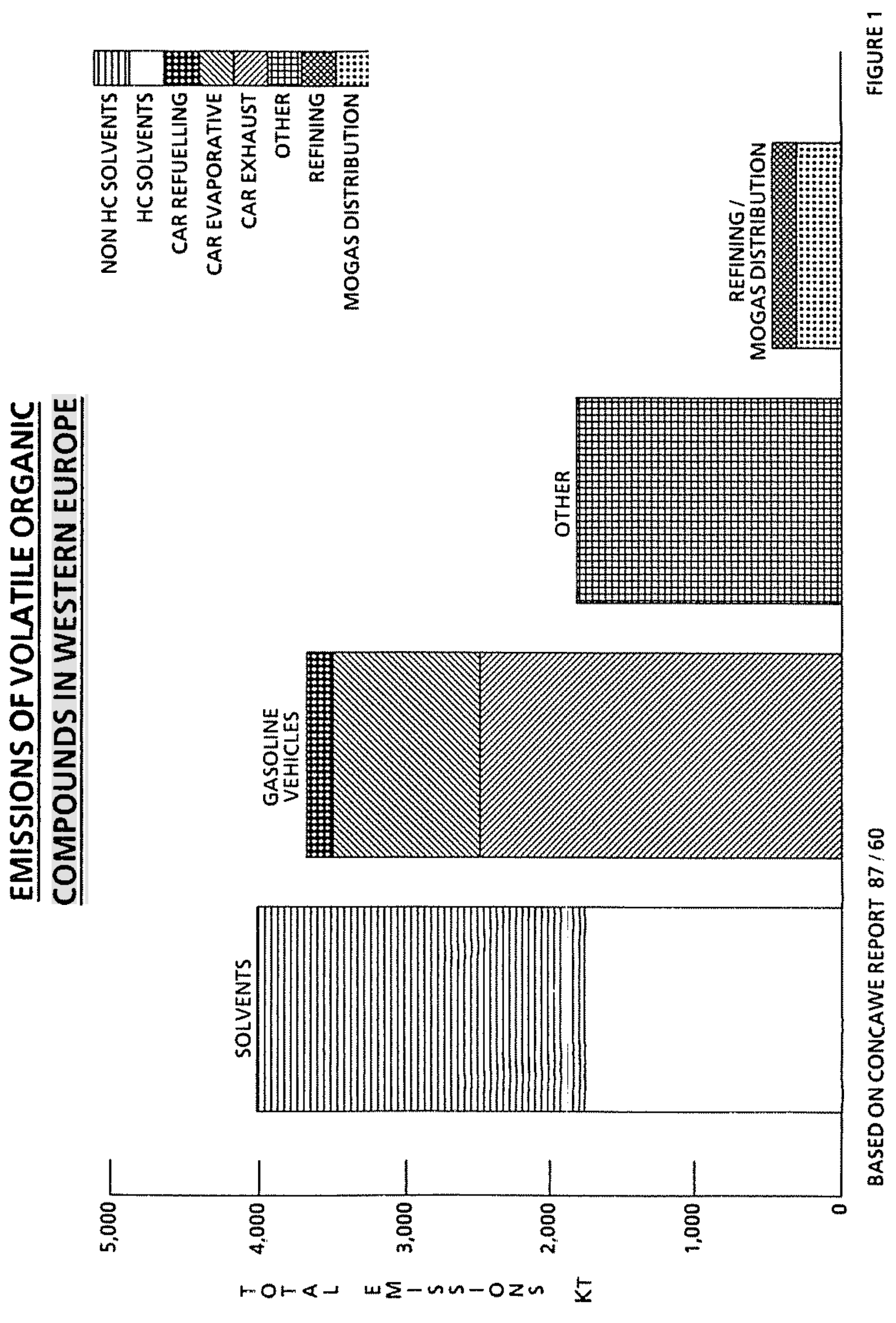

EMISSIONS OF VOLATILE ORGANIC
COMPOUNDS IN WESTERN EUROPE
NON HC SOLVENTS
HC SOLVENTS
CAR REFUELLING
CAR EVAPORATIVE
CAR EXHAUST
OTHER
REFINING
MOGAS DISTRIBUTION
TOTAL EMISSIONS KT
5,000
4,000
3,000
2,000
1,000
0
SOLVENTS
GASOLINE VEHICLES
OTHER
REFINING / MOGAS DISTRIBUTION
BASED ON CONCAWE REPORT 87 / 60
FIGURE 1

Fig. 2

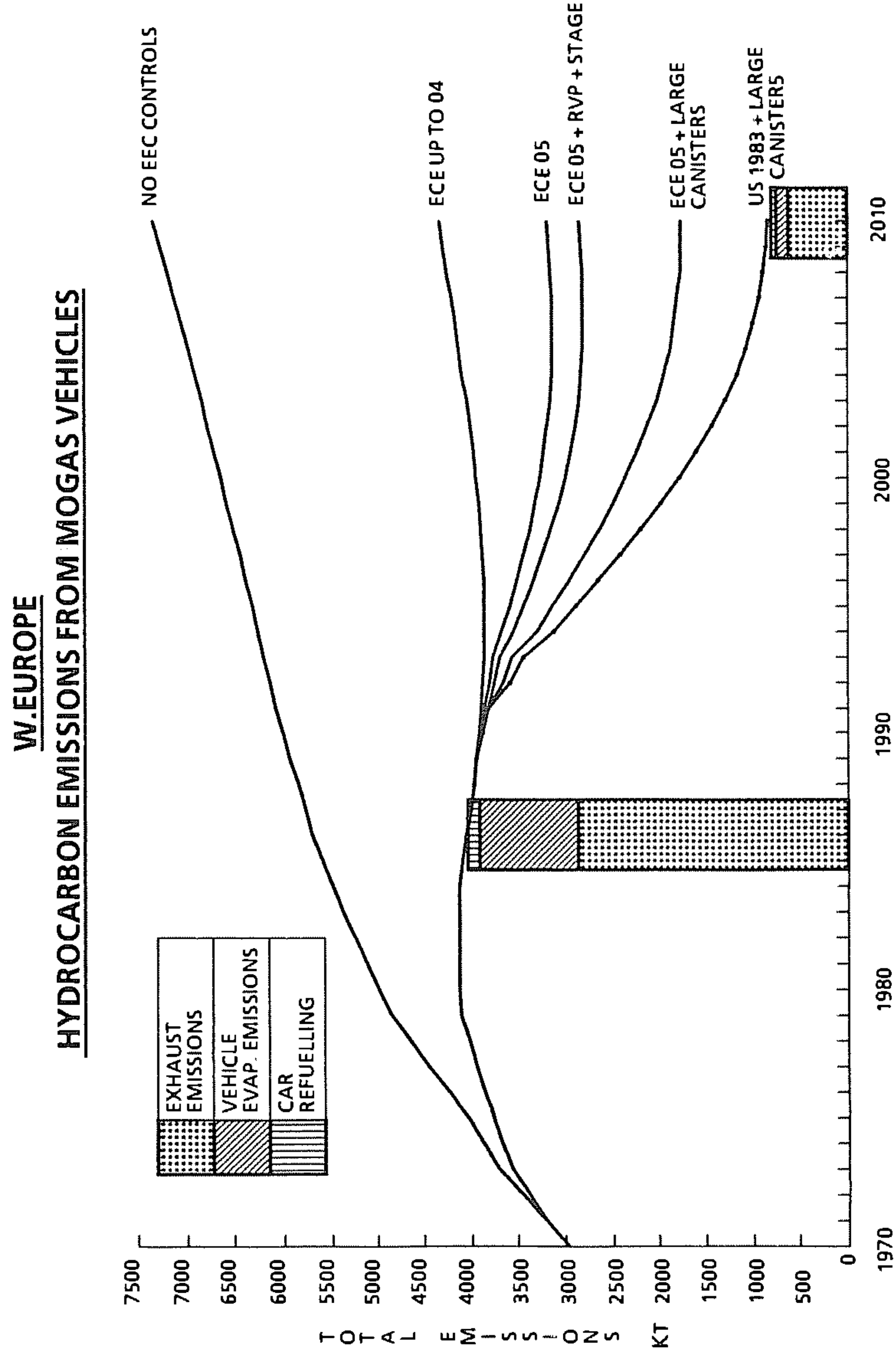
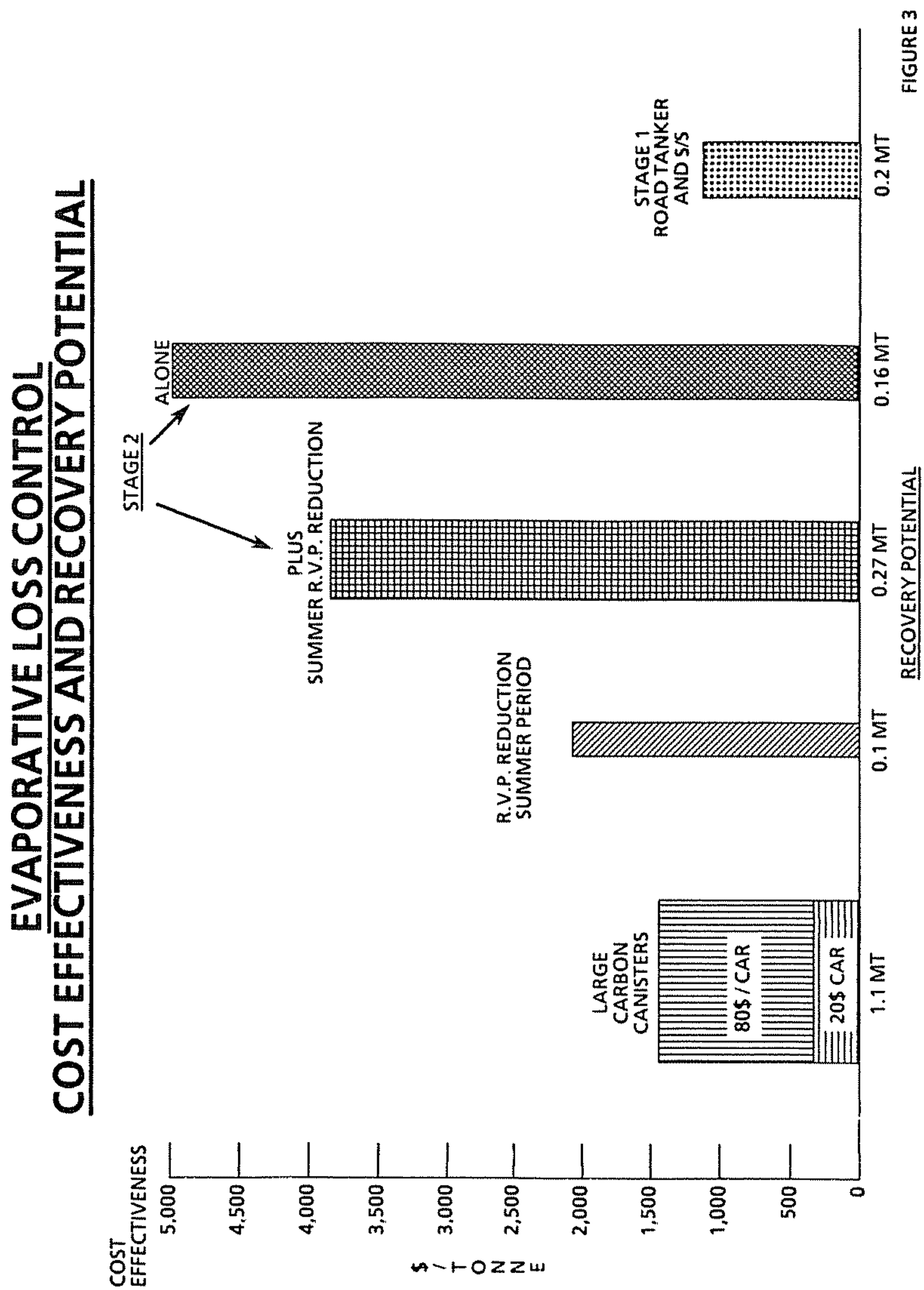


FIGURE 2

Fig. 3


EVAPORATIVE LOSS CONTROL
COST EFFECTIVENESS AND RECOVERY POTENTIAL
COST EFFECTIVENESS
$/TONNE
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
LARGE CARBON CANISTERS
80$ / CAR
20$ CAR
1.1 MT
R.V.P. REDUCTION SUMMER PERIOD
0.1 MT
PLUS SUMMER R.V.P. REDUCTION
0.27 MT
STAGE 2
ALONE
0.16 MT
STAGE 1 ROAD TANKER AND S/S
0.2 MT
RECOVERY POTENTIAL
FIGURE 3

VOLATILE ORGANIC COMPOUNDS

References are frequently made to hydrocarbon emissions in discussions of airborne organic compounds and their role in air pollution. However, hydrocarbon compounds consist only of carbon and hydrogen atoms whereas many of the organic compounds involved may contain additional atoms such as oxygen and halogens. For this reason the term organic compounds, which includes hydrocarbons, is the correct one.

When considering organic compounds, the volatility or vapour pressure of each individual compound is obviously important in determining the extent to which it will exist in vapour form in the atmosphere. The general term volatile organic compounds (VOC) is applied to those compounds which can exist in vapour form in the atmosphere.

In common usage the terms VOC emissions and hydrocarbon (HC) emissions are often used interchangeably. However, whereas the term VOC is always correct since it includes (volatile) hydrocarbons, the reverse may not be the case. Exceptions include particular emission sources such as those in the oil industry although even here the current use of oxygenated compounds in gasoline means that VOC emission provides the correct description in some instances.

The question of volatility is problematic since many relatively high boiling point compounds are detectable in the air as a result of emissions from liquids consisting of single compounds or complex mixtures such as gasoline. Where there is specific regulatory control of VOC emissions it has been necessary to define VOC in legal terms, e.g. the US Environmental Protection Agency definition is "organic compounds which have a vapour pressure greater than 0.13 kPa at standard atmospheric conditions, 20°C and 101.3 kPa". However in general, emission data are based simply on measured or calculated mass emissions without reference to any vapour pressure threshold.

In using VOC emission data the acronym NMHC is sometimes employed. NMHC refers to non-methane hydrocarbons and in such cases the correct description is often VOC emissions excluding methane. The reason why methane is frequently excluded is concerned with its ubiquitous nature, its non-toxicity, and its low photochemical activity relative to ozone formation. In the last case, since the concern with ozone has been mainly associated with short-term episodes of several days or less, some compounds other than methane may also be excluded from VOC emission inventories. However since methane may play an important role in increasing background levels of ozone and in other aspects of atmospheric chemistry, including the so-called greenhouse effect, it is attracting more specific attention.

In summary emission inventories should properly refer to VOC emissions and state whether or not methane or other compounds are excluded. If an upper vapour pressure threshold is included it should be defined. The term HC emissions should be applied to sources which emit only hydrocarbons.

HYDROCARBON EMISSIONS FROM GASOLINE PASSENGER CARS IN WESTERN EUROPE

The emission data in the CONCAWE Report Nos. 2/86 and 87/60 included estimates for exhaust emissions, evaporative and refuelling emissions. The basis for the calculations was set out in Report No. 2/86. The data on evaporative emissions was modified to take account of the most recent research data available to CONCAWE which suggested an understatement of evaporative emissions. These most up to date values in Report No. 87/60 indicated emissions from motor vehicles for the single year 1983 comprised:

	kt	%
Exhaust Emissions	2500	68
Evaporative Emissions	1010	27
Refuelling Emissions	180	5
Total	3690	100

CONCAWE believed it was important to provide interpretative data on the potential of various hydrocarbon control strategies to reduce emissions over time. This has been facilitated by the development of a computer model the scope and operation of which is described in Appendix 3. Using the model, estimates have been made of the impact of a number of control strategy options, that are being considered, out to the year 2010. These results are presented in Fig. 2. Although other assumptions may be readily evaluated, for the purpose of this report the cases presented are based on the following assumptions.

Case 1

Assumes no controls had or would be adopted by the EEC during the period 1970-201. This is therefore the "do nothing reference case".

Case 2

Assumes all EEC controls introduced since 1976 have been met by all new registrations from the first full year after the control standard was introduced. The current ECE 04 is assumed to continue out to the year 2010. Therefore this is the "do nothing more than is currently agreed case".

Case 3

This begins with Case 2 and then assumes that the ECE 05 regulations (Luxembourg Accord) as agreed on July 21st 1987, are met by all new registrations in the first full year after the control standards are introduced as stipulated by the directive, and thereafter to the year 2010.

Case 4

Is based on the same exhaust assumptions as Case 3, but additionally assumes that a 10% reduction in running evaporative losses is achieved by limiting European summer time RVP to a ceiling of 60 kPa. Also "Stage 2" is presented to achieve 50% coverage by 1995 and 100% coverage by 2000 and performs at 90% efficiency.

Case 5

Carries the same exhaust emission control assumptions as Cases 3 and 4, but running evaporative and refuelling emissions are assumed to be controlled by the introduction of large carbon canisters on all new registrations, according to the schedule required by ECE 05 for exhaust emissions. The efficiency of canisters has been assumed to be 90%.

Case 6

Is based on the assumption that the ECE 05 time schedule remains the same but that the emission control requirements are:

a) equivalent to U.S. 1983 standards for the exhaust;

b) require large carbon canisters to control running evaporative and refuelling losses.

A comparison for 1983 of the model data versus the data reported in CONCAWE Report No. 87/60 shows a good level of agreement and provides confidence in the predicted data.

	Model Data	%	CONCAWE 87/60	%
Exhaust Emissions (kt)	2952	71	2500	68
Evaporative Emissions (kt)	1010	25	1010	27
Refuelling Emissions (kt)	165	4	180	5
Total (kt)	4126	100	3690	100
Car Population (M)	115		115	

The variation on exhaust data is explained by the assumption in Report No. 87/60 which used UK Warren Spring Laboratory data for on the road exhaust emissions performance. The model data have been strictly constrained to a comparison of standards set by the legislation. As improved data on emission performance become available the model data can readily be updated.

The actual exhaust emission factors used on the model calculation are set out below.

	Large (g/km)	Medium (g/km)	Small (g/km)
Uncontrolled	3.76	3.11	2.663
ECE 15	2.947	2.438	2.086
ECE 01/02	2.508	2.075	1.775
ECE 03	2.213	1.838	1.567
ECE 04	1.597	1.455	1.313
ECE 05	0.375	0.462	1.125
Catalysts on all cars	0.375	0.375	0.375

CONCAWE COMPUTER MODEL FOR CALCULATING EMISSIONS FROM MOTOR VEHICLES

The model, developed during the first quarter of March 1987, is used to quantify the effects of regulatory scenarios and the effectiveness of various technical methods for controlling emissions.

The following briefly describes the scope and form of the model, the factors involved, the data required and calculation methods.

Scope of the model

The function of the model is to calculate emissions by processing data provided by the user, and to report the results in tabular and graphical form.

- o The model applies to the 17 countries of W. Europe, both individually and in selected groups, such as EEC 10 and 12, Big 4 and W. Europe.
- o Emissions include hydrocarbons, nitrogen oxides, carbon monoxide and particulates. Hydrocarbon emissions are further subdivided into exhaust, evaporative (including running losses, hot soak and diurnal losses), refuelling emissions and delivery losses from storage tanks at service stations. The model is being extended to include losses at terminals during tanker loading.
- o Motor vehicles include gasoline and diesel cars (large >2 litres, medium 1.4 - 2.0 litres, small <1.4 litres), light commercial vehicles and heavy goods vehicles.
- o The model takes account of differences arising from driving on motorways, rural highways and in urban conurbations.
- o Emission results are reported for the period 1970 to 2010.

Storage of datasets

The main variables involved in calculating emissions are:

- new vehicle registrations each year, car survival rate, type and size of vehicle, annual mileage and percentage on motorways/rural/urban, gasoline volatility, fuel consumption, air temperature and emission rates;
- data have to be provided by the user on each of these variables. A very useful facility is that up to 5 datasets

per variable can be stored in the model, each covering the period 1952 to 2010;

the program is run after specifying a dataset for each variable.

Total car population and age distribution

In the process of calculating emissions, an important preliminary step in the model is to determine the car population and age distribution of cars, each year and for each country, using the following data:

- new car registrations per annum from 1952 to 1986, and thereafter - the percentage estimated change in total car population;

- car survival rate in each country, defined as the percentage number surviving after 1,2.... x years, when the rate falls below, say 5%.

A partial check on the accuracy of survival rates is obtained by comparing calculated car populations against actual values published up to 1986.

Emission data and calculation methods

Experimental work has indicated that gasoline emissions are dependent on volatility, expressed in terms of Reid Vapour Pressure (RVP). To allow for the effect of RVP, data on emission rates can currently be entered in the model as a linear equation of the form $y = mx + b$, where:

y = emission rate
x = RVP
m and b = constants

One of these constants could, for example, be air temperature. More complex non-linear correlations would have to be adapted to fit the model.

However, where the correlation with RVP is not known, the model has the flexibility to work with individual values of emission rate.

Data inputs to the model are in metric units, and emission results are reported in kt/yr.

Data on hot soak and diurnal loss rates are entered as g/d per vehicle, which in conjunction with calculated car populations, are directly converted into total emissions kt/yr.

However, exhaust emissions and running losses which are entered in the model as g/km per car, use the data on annual car "mileage" (in kilometres) for conversion to kt/yr.

Similarly, refuelling and delivery losses entered in g/litre, require gasoline consumption data (litres/100 km) for conversion to kt/yr.