AIR POLLUTION CONTROL IN THE SÃO PAULO METROPOLITAN REGION: STATUS REPORT

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International Alternative Fuels Conference
25-28 June 1996
Milwaukee, Wisconsin, USA

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ABSTRACT

Air pollution in Brazil is a growing problem and it is closely related to industrial activities and motor vehicle usage.

The São Paulo Metropolitan Region (SPMR) is certainly the most difficult case to control due to its megacity characteristics and high pollution levels.

Control actions developed for the SPMR by CETESB, the São Paulo State Environmental Protection Agency, are commonly adopted by the Federal Government as national regulations.

This paper gives an overview about the air pollution problem in the SPMR and highlights the most important accomplishments.

The focal point of discussion is the control strategy adopted. Special attention is given to the impact of alcohol use as a motor vehicle fuel and strategy improvements are proposed.

I. BACKGROUND

For more than two decades CETESB, the São Paulo State Environmental Protection Agency, has been developing air pollution control programs in the São Paulo Metropolitan Region (SPMR) through a variety of strategies having achieved some very significant results.

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These programs were initially focused on public annoyance avoidance and afterwards directed to health protection. They were based on the command and control approach, involving air quality and emission standards, permits and licences, monitoring and selective enforcement of major industrial sources, according to the "ABC" curve methodology.

In addition, because of the unfavorable pollutant dispersion conditions during the may-august period, a set of more intense control activities, known as the "Winter Operation", is put in practice in order to avoid ocurrence of acute air pollution episodes.

Figure 1 shows sulfur dioxide (SO_2) ambient concentrations observed during the last 14 years. In fact the SO_2 air quality standard has been attained and this is the result of a control program that started in 1981 aimed to reduce SO_2 emissions by 80%. The strategy included emission control in industrial processes, reduction of sulfur content in industrial and Diesel fuels and fuel substitution by cleaner energy sources such as electricity and natural gas. It is estimated that 87% of SO_2 emission was reduced (1).

Table 1 shows the evolution of lead additives content in brazilian gasoline. In some parts of the country the levels of this toxic compounds was very high, reaching up to 0,8 ml/l. However, since 1991 lead additives were officialy banned to make possible the use of catalytic converters for gaseous emissions control.

Table 1 - Reduction of Lead Content In Gasoline

Year	Lead Content - ml/l	% Ethanol
1977	0,236	4,5
1979	0,145	15,0
1981	0,114	20 ± 3
1983	0,087	20 ± 3
1985	0,120	22 ± 1
1986	Motor Vehicle Emission Control Program Enforcement	
1987	0,060	22 ± 1
1989	0,060	22 ± 1
1991	nihil	22 ± 1
1992	First vehicles equiped with catalytic converters	

It has to be recognized that the use of ethanol as a blending component of brazilian gasoline since late 70's, although did not have an environmental purpose at first, played a fundamental role on the end of lead additives use.

Figure 2 demonstrates the effect of lead use on ambient lead concentrations. In 1978 the recorded average 3-month lead peak in the SPMR was 1,6 g/m^3, therefore above the World Health Organization recommended a standard of 1,5 g/m^3. Since 1983, with the increasingly and continuous use of ethanol in gasoline, the ambient levels were reduced on the average by at least 70% and recorded 3-month average values were kept around 0,2 g/m^3. More recent data confirms the low lead ambient levels in the SPMR.

Figure 3 clearly shows the importance of ambient lead reduction on human health. In fact, it is recognized that there is a strong correlation between the use of lead additives and blood lead levels (2).

With regard to suspended particulate matter (SPM), CETESB started a control program in 1979, with a goal of 85% emission reduction in 5 years, through the strategy of requiring best available control technology from major industrial sources.

Program evaluation results showed an estimated emission reduction of 97% by the end of 1986. However, the impact of this effort on air quality improvement was minimal (1).

Present ambient particulate concentrations are still high in the SPMR as can be seen on Figure 4.

It is believed that this strategy did not show the expected efficacy because the spatial distribution of the emission sources was not considered and because the relative importance of vehicular emission, particularly from Diesel vehicles, was not taken into account as an important factor in the control planning process.

This fact is of paramount importance because particles emitted by vehicles are within the respirable range (PM10) and considered to affect health significantly.

Receptor model studies conducted in the SPMR with PM10 particles (smaller than 10 microns) show that:

- About 50% are emitted by vehicles.
- Between 20% to 30% are ressuspended from streets by wind action and other causes, mainly vehicular traffic.
- Between 10% to 20% are sulfates, formed in the atmosphere due to the presence of sulfur oxides, which currently are predominantly emitted by the vehicle fleet.

It is important to note that carbonaceous content in São Paulo particulates is considerably higher than in various U.S. cities, as shown in Figure 5, suggesting that combustion processes and, particularly vehicles, must be strongly controlled.

Following the above referred control programs, an updated emission inventory provided a clear picture of motor vehicles importance as major pollution sources in the SPMR, as shown in Figure 6.

Light and medium duty vehicles fueled either with gasohol (gasoline plus 22% ethanol) or with neat ethanol are responsible for most of the carbon monoxide (CO) and organic compounds (HC). On the other hand, the heavy duty Diesel vehicles respond for most of nitrogen oxides (NO_x) and sulfur oxides (SO_x) emissions. In terms of particulates, vehicles respond for 40% of emissions.

It should be noted that the 10% difference between the receptor model results and particulates inventory estimates is within the acceptable variation range due to methodology differences.

With regard to ambient CO levels, the number of air quality violations has been very high, as shown in Figure 7. However, during last years a slight downward tendency in peak concentrations was observed, despite of the continuous vehicle fleet growth. It is thought that this effect is due to two main reasons:

- Emission reductions required since 1988 for new vehicles within the framework of the national motor vehicle air pollution control program (PROCONVE);
- Intensive use of ethanol either as a neat fuel or blended with gasoline.

It should be noted that blendind ethanol with gasoline brought down CO engine-out emissions by 50% in the fleet average.

Figure 8 shows the ozone (O_3) air quality violations evolution. For this particular pollutant, CETESB's monitoring network was affected by a number of problems which caused measurement interruptions. Nevertheless, the available data shows that the number of violations has been kept within a certain range, despite vehicle fleet growth and, consequently, increased alcohol use.

Therefore, although there is not a clear answer yet about the actual role of ethanol use on O_3 formation, the available information suggests that there are no evidences that massive ethanol use would be the culprit for O_3 peaks occurrence.

Curiously, during the last two years an upward tendency of O_3 peak occurrence caught CETESB's attention.

Any plausible explanation would have to consider the following important and influential aspects:

- Since July 1994 the brazilian economic stabilization program resulted in a significant increase of vehicle utilization and fast vehicle fleet growth. Consequently emission has increased.
- Due to the reduction of ethanol production and lack of significant incentives for alcohol vehicles, sales of gasohol fueled vehicles boomed. Coincidentaly, an unusually high O_3 peak was observed on July 31, 1995, when ethanol substitution by gasohol was clearly becoming the new trend.

Since it is known that O_3 formation is heavily governed by the HC/NO_X ratio and by pollutant photochemical reactivity, among other parameters, and that gasoline use growth might be capable of changing the mix of organic compounds in the atmosphere and therefore affect photochemical reactivity, it can be inferred that the substitution of alcohol by gasohol and the atmospheric increment of gasoline use by-products could be causing these high O_3 peaks. Further monitoring studies will have to be conducted to evaluate the O_3 problem in the SPMR.

II. MOTOR VEHICLE POLLUTION CONTROL STRATEGY

Due to the evident need to control motor vehicle generated pollution, particularly in the metropolitan areas, CETESB proposed to the Federal Government, in 1985, a comprehensive vehicle emission control program (PROCONVE) which is based on the following strategy:

1) Development and implementation by the automotive industry of new concepts and technologies to reduce substantially emissions from new vehicles.

The result of this requirement was an emission reduction of about 80%, over a period of only 8 years, which correspond to the first and second steps of the control program.

The emission standards for new vehicles were phased in progressively and became very stringent in a relatively short period. As shown in Figure 9, standards for light duty vehicles (LDV) were enforced in three steps, as well as for light duty trucks (LDT) in two steps, and for heavy duty vehicles (HDV) in four steps. As a result, starting January 1997 and 1998, LDV and LDT will be required to attain U.S. standards, respectively, which represent current international state-of-the-art emission control techonology. Similarly, HDV, which tend to have similar use characteristics as in Europe, will attain the current EURO II standards starting January 1998 for buses and January 2000 for trucks.

This means that by the end of this century Brazil will match with the most developed countries in the field of vehicle pollution control technology.

With regard to emission test and certification procedures, the standardization and harmonization process adopted in Brazil, which are compatible with the U.S. and European procedures, makes possible the exchange of technologies and technical data. Because of the good results brought by this process, which started in Brazil in 1986, it was adopted in 1992 as a normative by the MERCOSUL countries (Argentina, Brazil, Uruguay and Paraguay).

2) Fuel quality improvement.

The major achievements were the ban of lead additives, the reduction of Diesel sulfur by about 50% and the legal requirement for 22% anhydrous ethanol addition to gasoline.

This last measure has a number of advantages such as the possibility to keep during gasoline formulation the levels of the highly photochemically reactive olefins and the toxic aromatics at its minimum.

3) Implementation of inspection and maintenance programs for in-use vehicles.

This requirement, widely adopted in the U.S., Japan and elsewhere, incentives the motor industry to produce more durable and reliable vehicles, requires the public to actually pay attention to maintenance and increases its awareness on pollution matters, improves mechanics technical knowledge and promotes better services from the repair shops. The major goal is to keep the in-use fleet emissions the lowest as possible in a cost effective way.

It is expected that an I/M program will be implemented in the SPMR in 1997 and a 20% to 30% improvement in ambient CO concentrations be achieved within a period of 5 years.

4) Field inspections and enforcement.

The practice of field inspections and enforcement of in-use emission standards is particularly efficient with Diesel vehicles smoke emission control. In addition, it can be a complementary action to the I/M program with all types of vehicles.

Currently, a strong effort to cut down excessive Diesel smoke emissions from 40% to less than 10% is under way in the SPMR.

Since January 1st 1996, fines for excesive smoke increased and are around US$450,00 for the first offense. This value doubles for the second time offense.

Curb side CO and HC emission tests are being considered for the future, after the implementation of the I/M program.

Although it is recognized that the above mentioned actions can bring substantial environmental benefits, motor vehicle usage is increasing tremendously. By the end of 1996, it is expected that the SPMR will have a fleet of more than 5 million vehicles. Considering that the fleet in 1989 was around 2,5 million, this means a 100% fleet increase in only 7 years! Therefore, it is believed that the so-called "non-technological pollution control measures", such as expansion and improvement of public transport, carpooling, flex-time, automobiles usage restriction, expansion of clean energy sources, etc. are fundamental elements in any sound strategy aimed to improve life quality in urban regions.

III.THE SINERGISM OF ALCOHOL USE AND POLLUTION CONTROL PROGRAMS

Despite the fact that Brazilian Ethanol Program (PROÁLCOOL) was originally created for fuel supply purposes rather than pollution control, significant vehicle emission reductions were achieved.

As a gasoline additive, ethanol is distinguished by its low photochemical reactivity and toxicity, as shown in Table 2. Additionally, some reactive and toxic hydrocarbons can be removed from gasoline, since ethanol also improves the octane index and substitutes aromatics and lead compounds commonly used for octane boosting.

Table 2 - Maximum Reactivity Increase			
Substance	**g O_3 / g subst.**	**Substance**	**g O_3 / g subst.**
propene	6.6	ETBE	1.33
isoprene	6.5	iso-butane	0.85
formaldehyde	6.2	ethanol	0.79
1-butene	6.1	n-hexane	0.61
ethene	5.3	MTBE	0.47
0-xylene	5.2	methanol	0.40
iso-butene	4.2	propane	0.33
acetaldehyde	3.8	methane	0.0102
toluene	1.9		

Furthermore, the addition of 22% ethanol to brazilian gasoline reduces the sulfur content in the same proportion, since ethanol is pratically sulfur free. This decreases the average emission of SO_x and avoids lower catalyst durability and loss of efficiency.

However, the most important advantage of ethanol addition to gasoline is the reduction of carbon monoxide and hydrocarbons emission provided by ethanol's oxigen content addition to the combustion process because ethanol has low molecular weight, simple atomic bonds and supports a continuous and smooth flame without misfiring at an extended range of air excess in relation to fuel.

Also, since ethanol doesn't have sulfur and supports combustion under oxigen excess, it reduces or even eliminates the rotten egg smell created by catalytic converters of mistuned vehicles. Such a problem commonly occurs due to the H_2S formation in the catalytic converter when fuel in excess creates a reductant atmosphere and blocks the sulfur oxidation to SO_2.

The evolution of LDV CO, HC and NO_x emission is shown in Figure 10. The 22% addition of ethanol to gasoline started in 1981 and responds for a significant reduction of CO and HC emission of the existent vehicles, without any special tunning or modification. Despite of this gain, ethanol fueled vehicles still have an advantage of 20% to 30% when compared to a similar gasohol vehicle, within any model-year or with the same technological pack. This figure also shows the strong influence of PROCONVE (limits are represented by the upper line) on the average emission levels tendency, where the 1997 targets seem to be clearly attainned. It is worth to note that some brazilian vehicle models are already in compliance with these limits since 1993.

Figure 11 shows the same tendency for total aldehydes and evaporative emissions. It is important to note the proportionally higher aldehyde emissions of ethanol vehicles when compared to gasohol vehicles. However, there were no air quality standards nor emission limits for aldehydes at the beginning of PROÁLCOOL. Thus, the strategy was to establish a quite feasible emission standard in 1992 to avoid the development of catalyst formulations which could favour aldehydes increase.

Giving time for the technological development a new goal was set for 1997. The new aldehyde standard will require the same aldehyde levels observed in gasoline vehicles, which so far have not been taken as the main factor of air pollution problems in large cities. Thus, as ethanol vehicles will have the same levels of aldehydes as older gasoline cars, it is assumed that this problem is under control. Since current average aldehyde emissions are close to the 1997 target, both for the catalyst and the fuel injection equipped vehicles, the emission control program achieved its goal.

Figure 12 shows an important comparison between the formaldehyde, acetaldehyde and carbon monoxide concentrations in the athmosphere. It is clear that these pollutants come from vehicles, since both species of aldehydes follow the CO tendency along the entire day. However, aldehyde ambient concentrations have been maintained at low levels, despite the high emission observed, mostly caused by a considerable number of pre-control vehicles, pointing that PROCONVE's target is very conservative and safe from the environmental point of view. Even under difficult dispersion conditions in the athmosphere, as it occurs inside tunnels, aldehyde concentrations are low. Samples taken in the "Túnel 9 de Julho" in São Paulo showed 111 ppm. and 132 ppm. for formaldehyde and acetaldehyde respectively, much lower than the TLV's for these substances.

It is also important to comment that the present average aldehyde emissions are under 70 mg/km for the brazilian ethanol vehicles, while the imported gasoline vehicles, which comply with the U.S. emission regulations, have aldehyde emissions under 14 mg/km (detection limit of the method). In general, the exhaust emissions are qualitatively compared in Figure 13, between both gasoline and ethanol fueled vehicles, showing significant reductions on the medium and high reactivity organic compounds (3).

Figure 14 compares the organic exhaust emission and the fuel chromatograms, showing that fuel composition strongly affects exhaust emission characteristics.

Comparing the former brazilian gasoline (direct distillation), the premium grade cracked gasoline (Petrobrás' proposal for the future to be used with only 10% ethanol) and the present base gasoline (commercially available, but analysed after ethanol extraction), one can see in Figure 15 that many different substances are present in the newer formulations to provide the necessary octane index independently of ethanol addition (4).

Unfortunately, these substances have high molecular weight and are policyclic and aromatic hydrocarbons, hyghly toxic and in some cases carcinogenic.

These chromatograms make evident the brazilian oil sector's tendency to give lower priority to enviroment issues and maintaining independence of ethanol use for octane rating purposes. However, this practice is not recommended since oxigenates addition allows the elimination of such harmful compounds, and makes gasoline reformulation a reality, with low olefinic, aromatic and sulfur contents.

It is worth of note that the U.S. reformulated gasoline resulted from an intelligent strategy of ARCO - Atlantic Richfield Co., looking for a better competitiveness of gasoline in the "clean fuels" market (5).

Considering ethanol's massive use in Brazil for two decades, it is important to say that there are no evidences of public complaints or deleterious health effects. So, giving priority to other oxigenates usually less known is a nonsense, when ethanol is available.

Other additives can also be used in reformulated gasoline, and MTBE is favoured in comparison to ethanol due to its lower influence on gasoline vapor pressure and VOC emissions, although ethanol increases RVP in about 10% only. This reason limits ethanol use in critical areas in terms of VOC and ozone levels. In the other hand, ethanol has twice as high oxigen content than MTBE, which makes it more effective in the CO emission reduction and doesn't produce other important calateral effects as shown above.

A further reason that favors MTBE use is the fact that oil companies have high commercial interest in its use, because it is also a petrochemical product.

V. FUEL STRATEGIES

Diesel engines are still considered the most energy efficient alternative among current vehicular options. This fact is often used to justify an expansion of Diesel use as a means to extend oil availability in the future. However, the oil refining process does not produce only Diesel fuel and, because of crude oil and refining process characteristics, the Diesel/gasoline ratio has a limited flexibility. In Europe, Diesel oil demand is slightly higher than gasoline production and therefore some countries import Diesel fuel. Quite a different picture is observed in the U.S., where gasoline consumption is twice as high as Diesel demand and gasoline imports are needed.

Therefore, depending on local fuel type usage, demands on the fuel industry can be quite diferent.

In the brazilian case, as shown in Figure 16, gasoline demand is only a half of Diesel demand and this unbalanced situation requires Diesel imports. However, if one would consider both alcohol and gasoline demands as a single fuel source for LDV's, the situation would have a better balance as it occurs in Europe. On the other hand, because of alcohol use there is a gasoline surplus which has to be exported. Therefore, it becomes clear that substitution of fossil fuels by alcohols or other alternative fuels certainly creates a market dispute, which puts strong economic arguments against the new alternative and needs to be carefully managed.

In Brazil the problem is not the alternative fuel, but the exaggerated Diesel oil use which also causes air pollution in excess, as a result from the priority given to road transportation in the last 40 years.

Thus, transportation modes have to be revised to better balance different fuel demands and energy savings offered by railroads and navigation.

Such strategy could dramatically reduce vehicle emissions, since truck use could be minimized in favour of more efficient and less polluting transportation systems. This picture clearly shows the need for an integrated tranportation-energy-emission matrix solution.

It is worth of note that it is possible to implement complementary strategies based on fuel composition reformulation, in a significantly shorter time than the required for a transportation system change. Under this strategy, and looking for enviromental and market gains, some U.S. oil companies introduced the "Reformulated Gasoline - RFG"; therefore, enhancing the oil derived fuels competitiveness in the "clean fuels" market.

The R.F.G. concept is ilustrated in Figure 17. Firstly, some toxic and reactive components are transferred from current gasoline to fuel oil, which can be burned more completely under better combustion conditions. Secondly, other components, such as methane and butane, and oxygenated organic compounds are added to gasoline, in order to have a new formulation, but with the necessary requirements needed for adequate vehicle performance, and less harmfull to the enviroment.

Considered within this strategy, ethanol addition to gasoline could bring many advantages to the control of volatile organic compounds - V.O.C. and their effect on ozone formation, in addition to its recognized CO reduction capability. The key question is finding a compromise point between fuel vapor pressure regulatory requirements and volatility characteristics of the reformulated base gasoline. Considering that this compromise is technically feasible, the question becomes a political and economic issue.

Compressed natural gas - C.N.G. is also an important item in the alternative fuels scenario. C.N.G. vehicles have a very low emission potential, because their design includes high tech systems such as electronic gas injection and closed loop 3-way catalysts. Carburetted engines converted to C.N.G. operation are not as clean as thought and don't help environment protection, unless they are carefully converted with kits especially built and certified for this purpose.

The quality control of current engine conversion to C.N.G. is the main difficulty in its program and, consequently, governmental audits are expensive. However, a pilot program for engine conversion helps technological development, despite the fact that the cleanest engines are usually designed by car manufacturers and supplied as original engines in new vehicles. C.N.G. can be used also as an alternative for Diesel vehicles, helping to eliminate smoke and reduce significantly organic and sulfur oxides emissions. In addition, as is the case in Brazil, a program aimed to convert urban buses and urban delivery trucks would certainly ease the Diesel / gasoline unbalance.

With regard to C.N.G. use as a substitute of gasoline, this puts C.N.G. under the same market competition perspective, as discussed earlier. In addition, environmental benefits from a C.N.G. program directed to LDV's will come necessarily in a medium/long term basis, depending on requirements such as availability of C.N.G. distribution networks, conversion kits and services quality, availability of custom made engines for C.N.G. and gasoline substitution rate by C.N.G.

Returning to the evaluation of ethanol use, there is another important aspect worth of mention: its physical and chemical properties are in between the methanol and gasoline characteristics. Based on this fact, it is possible to make methanol-ethanol-gasoline blends that, if adequately and carefully balanced, will result in equivalent performance, fuel economy and emission results on engines designed to burn neat ethanol.

Thus, the renewable fuels supply problems, induced by agricultural production variability can be solved since it is possible to balance the differences of ethanol production/demand, through methanol and gasoline addition to ethanol.

Since 1990, the brazilian ethanol program has taken advantage of this possibility, using a blend of 33% methanol+60% ethanol+7% gasoline -"MEG" in the São Paulo Metropolitan Region. This is a simple, reliable, safe, efficient and quick alternative, which can be used regionally and seasonally without any conflict of different fuel vehicle supply, either neat ethanol or MEG. The emission levels remain under control, and fuel supply is assured.

According to the same reasoning, there are alternatives to ethanol addition to gasoline, if needed. In this case, it is necessary to formulate the new additive carefully to maintain the same engine air/fuel ratio requirements, taking into account the oxigen content, the differences in viscosity, density and other parameters in the additives. Since methanol needs a co-solvent, the amount of 22% of ethanol, already used in brazilian gasoline, cannot be totally substituted. Other oxygenated compounds can be used in this case as complements, however their oxygen content is lower than that of ethanol.

These new alternative fuel formulations bring into consideration a new opportunity, which is to associate the ethanol program to methanol production, using sugar cane bagasse and leaves, and other solid wastes or natural gas, as methanol production feedstock. This could turn the whole Program more attractive, creating other by products and improving the use of other existent resources which are not being considered.

It is worth to remember that the energy wasted when burning the leaves, before the sugar cane harvest, is comparable to the ethanol energy content produced in the same area. If methanol were produced instead, a significant economic saving would be added to the enviromental gain of ethanol's production-usage cycle by avoiding the leaves open burning emissions.

V. NON TECHNOLOGICAL MEASURES

Along with the previously discussed control actions, traffic management, new policies for the transportation system and land use are necessary to complement and assure the effectiveness of the air quality control measures.

It is known that car use is excessive in many parts of Brazil, and the SPMR is not an exception. The reasons are numerous and vary from lack of good quality public transportation, heavy reliance on the automobile (in a blend of preference and necessity) to low cost of fuels.

In order to reduce excessive driving, CETESB and the São Paulo State Secretary of the Environment conducted jointly, in 1995, during one week, a pilot program based on a voluntary automobile usage restriction, based on the final car plate number. Everyday two final numbers were not "allowed" to circulate, representing 20% of the car fleet.

The voluntary program showed along the week an average of 35% public participation, which represents 8% reduction on the average number of daily circulating vehicles. This traffic reduction associated to the increase in the average speed, which also reduces the remaining vehicles emission, produced an interesting result: driving restriction days when compared with days with similar metereological conditions showed lower CO concentrations.

It is evident that an one week pilot program will not generate statistically significant air quality data. Therefore the lower CO concentrations have limited validity and should be considered with care.

The São Paulo State Government is proposing the vehicle circulation restriction as a permanent pollution control policy during the "Winter Operation" period. Legal authorization from the State Assembly is required because the restriction will be compulsory and offenders will be fined.

VI. FUTURE DEVELOPMENTS

It is apparent from the points discussed in this paper that to effectively control air pollution in the SPMR, motor vehicle emissions will have to be targetted taking into consideration:

- Emission standards and technical requisites update for new vehicles;
- Implementation of In-Use Vehicle Emission Inspection Programs;
- Fair energy policies that could balance the energy matrix and assure favorable conditions for clean and renewable sources of energy;
- Oil derived fuels reformulation for lower environmental impact;

- Strengthening of field enforcement activities, particularly those directed to reduce Diesel smoke;
- Expansion and improvement of the public transportation system;
- Implementation of fuel vapor recovery systems;
- Adoption of "non-technological pollution control measures" such as traffic restrictions, congestion tolls, traffic signal improvements, high occupancy vehicle lanes, variable working hours and carpooling;
- Economic instruments to incentive vehicle scrappage, to overcharge fuels use selectively, to regulate and price urban parking, to subsidise public transport and to tax vehicle ownership selectively.

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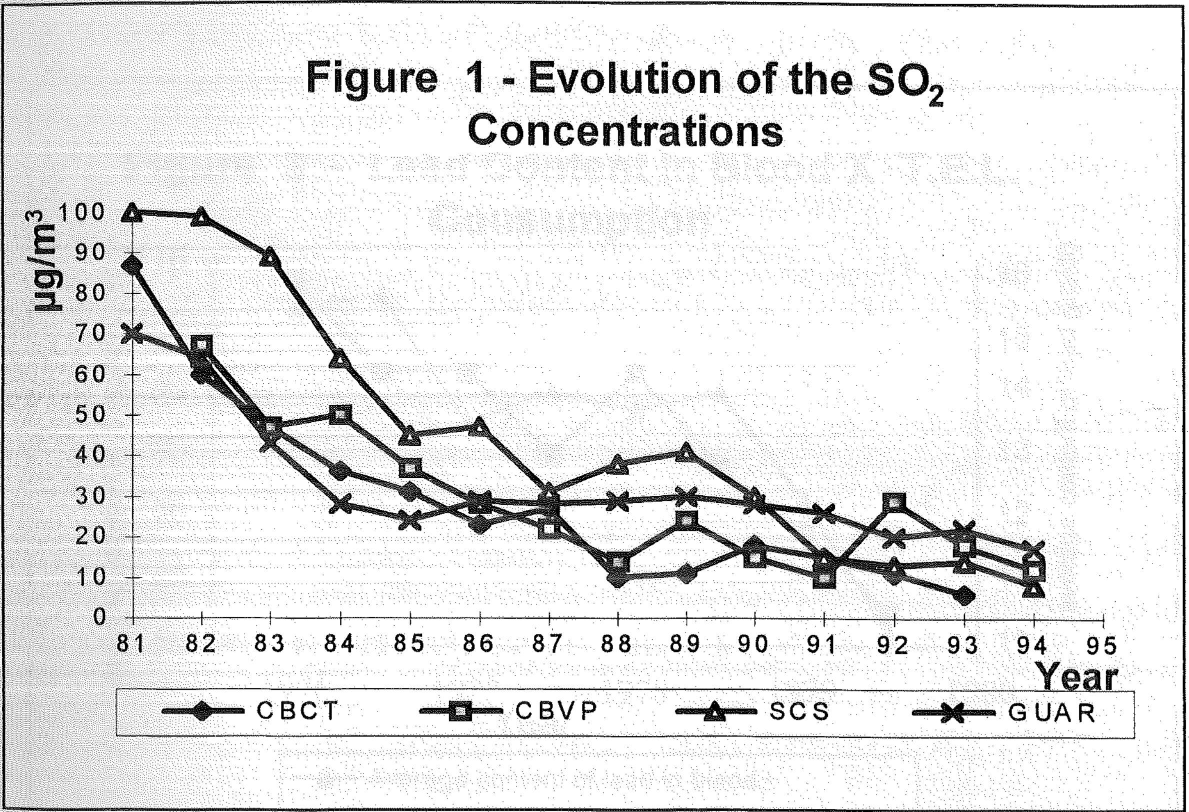


Figure 1 - Evolution of the SO_2 Concentrations
µg/m³
100
90
80
70
60
50
40
30
20
10
0
81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
Year
CBCT
CBVP
SCS
GUAR

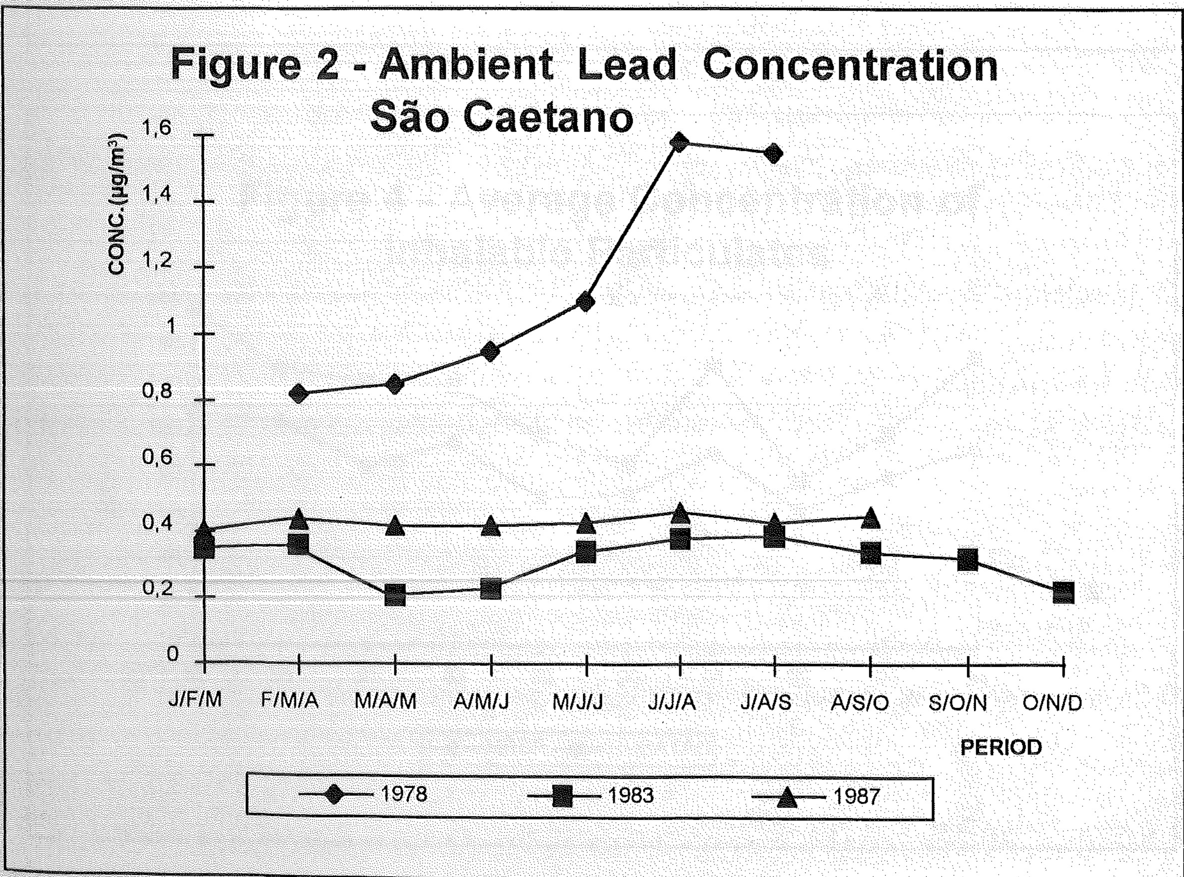


Figure 2 - Ambient Lead Concentration São Caetano
CONC.(µg/m³)
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
J/F/M F/M/A M/A/M A/M/J M/J/J J/J/A J/A/S A/S/O S/O/N O/N/D
PERIOD
1978
1983
1987

Figure 3 - Lead Content in Blood X T.E.L. Consumption

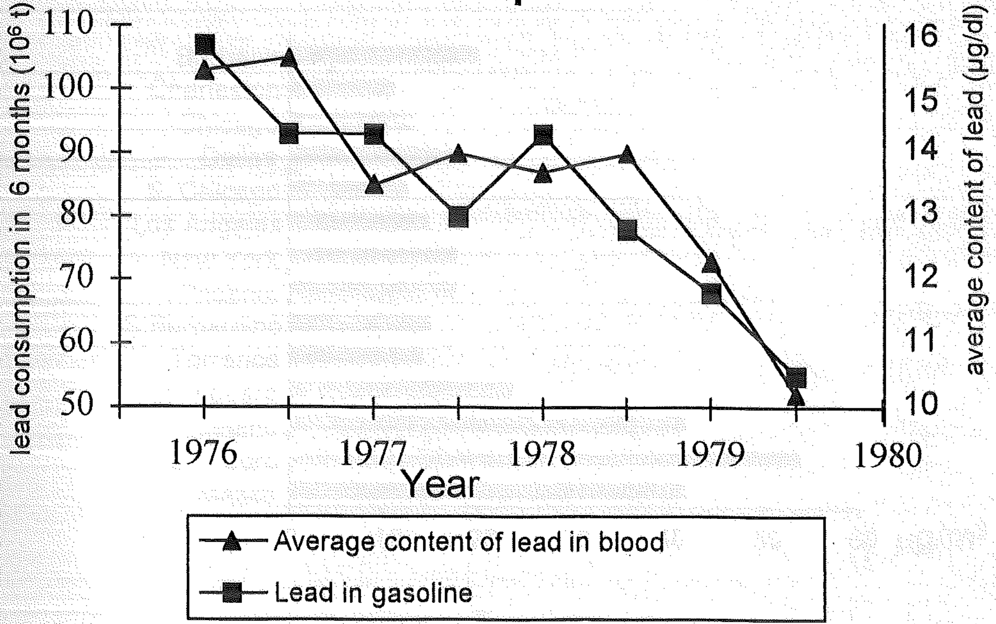


Figure 4 - Average Concentration of Inhalable Particulates

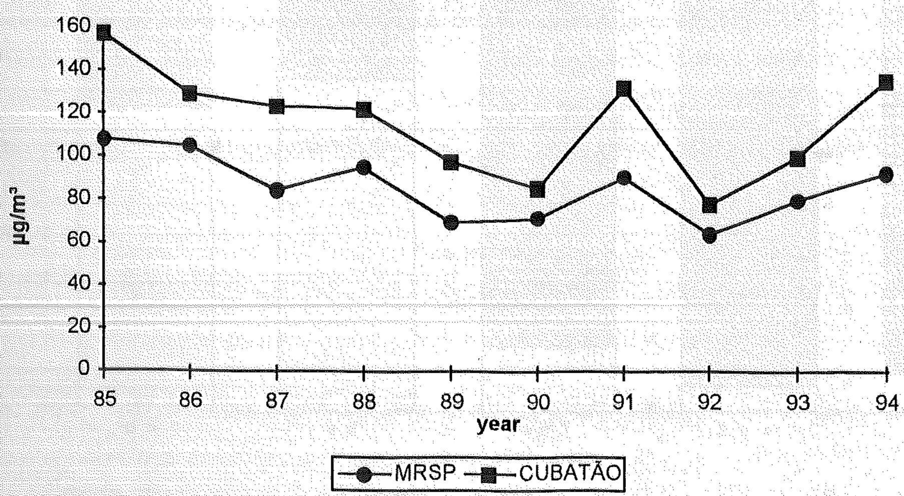


Figure 5 - Carbonaceous Concentration in Particulate Matter in São Paulo and Some US Cities

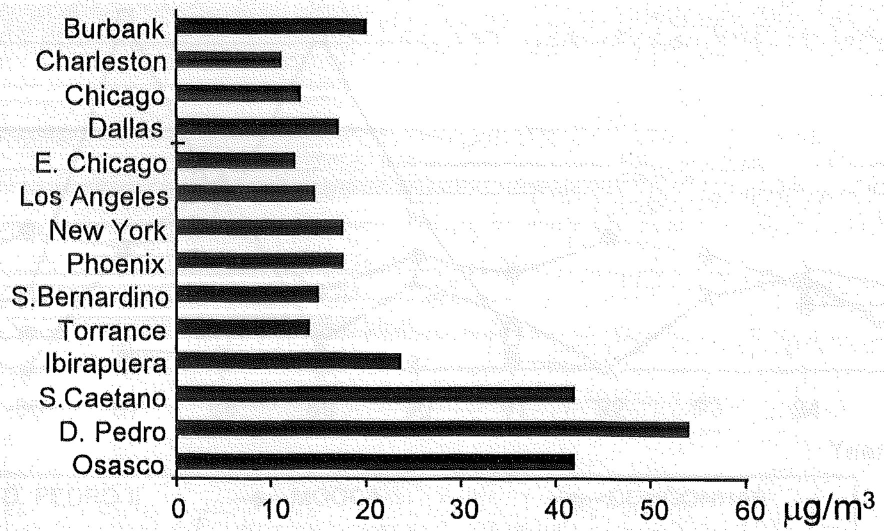
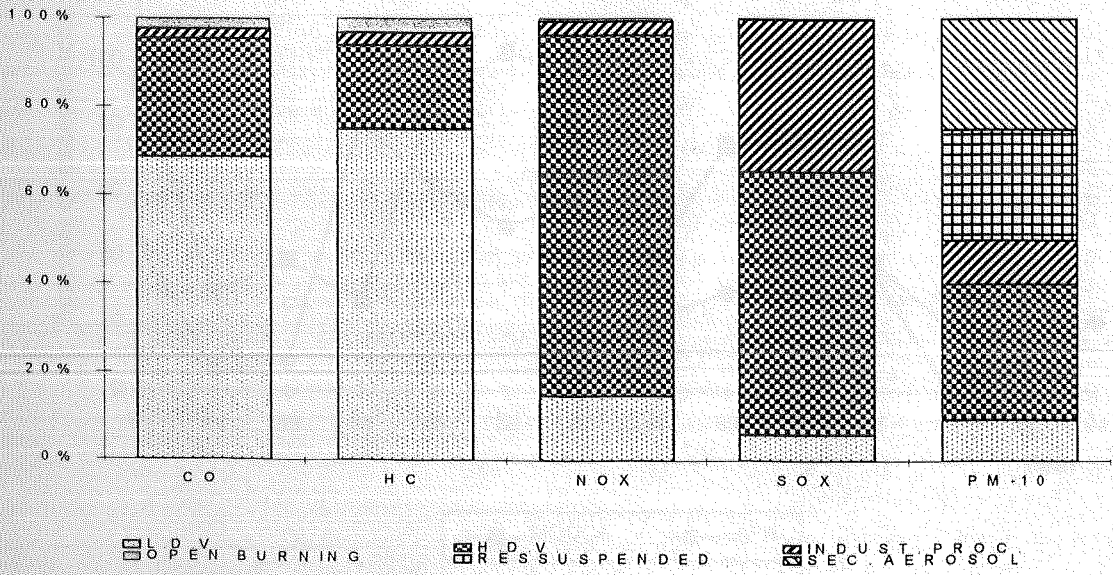


Figure 6 - Relative Emissions



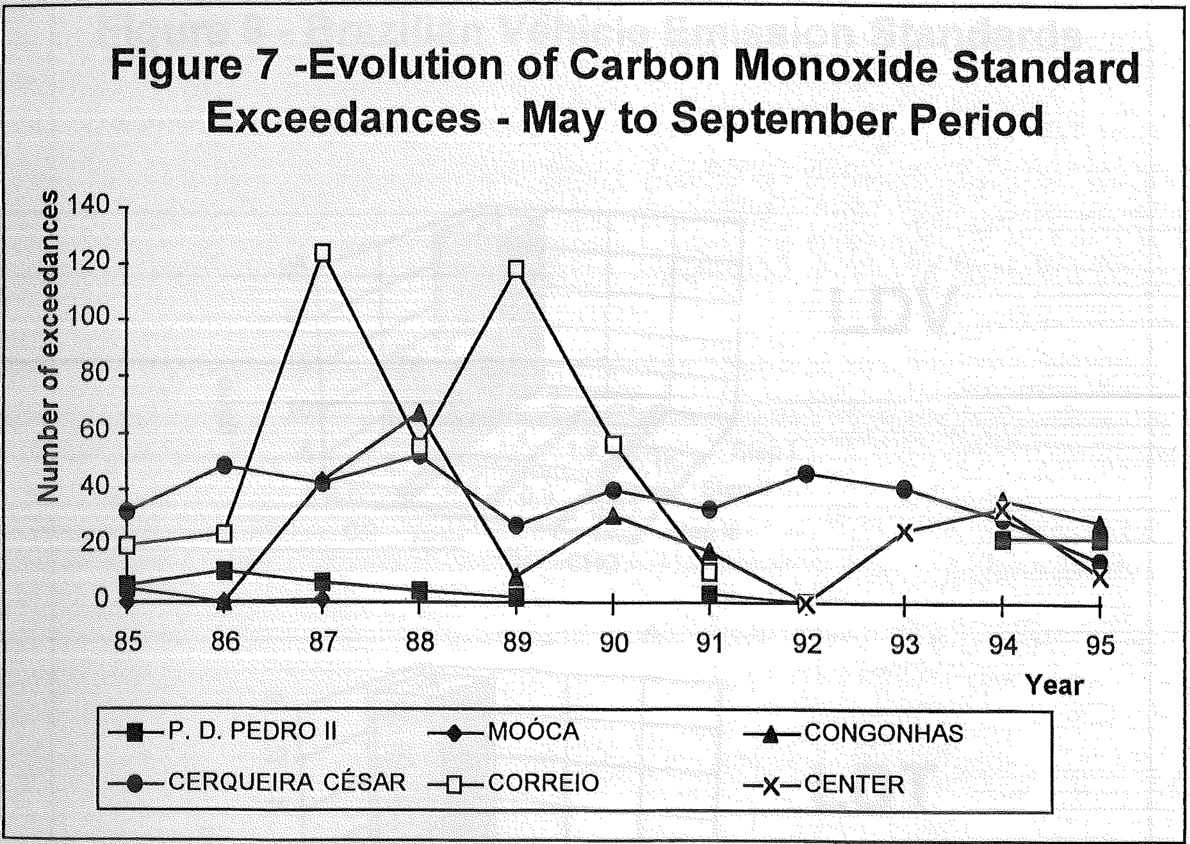


Figure 7 -Evolution of Carbon Monoxide Standard Exceedances - May to September Period
Number of exceedances
140
120
100
80
60
40
20
0
85
86
87
88
89
90
91
92
93
94
95
Year
P. D. PEDRO II
MOÓCA
CONGONHAS
CERQUEIRA CÉSAR
CORREIO
CENTER

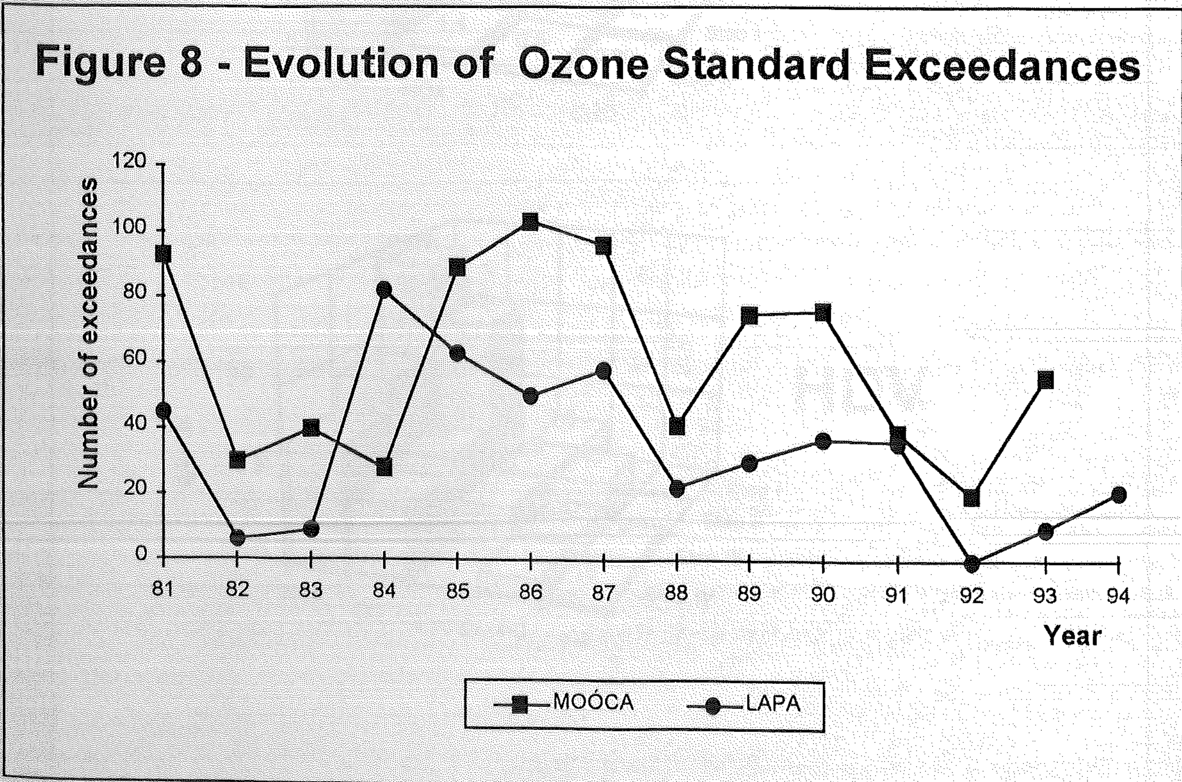


Figure 8 - Evolution of Ozone Standard Exceedances
Number of exceedances
120
100
80
60
40
20
0
81
82
83
84
85
86
87
88
89
90
91
92
93
94
Year
MOÓCA
LAPA

Figure 9 - Brazilian Vehicle Emission Standards

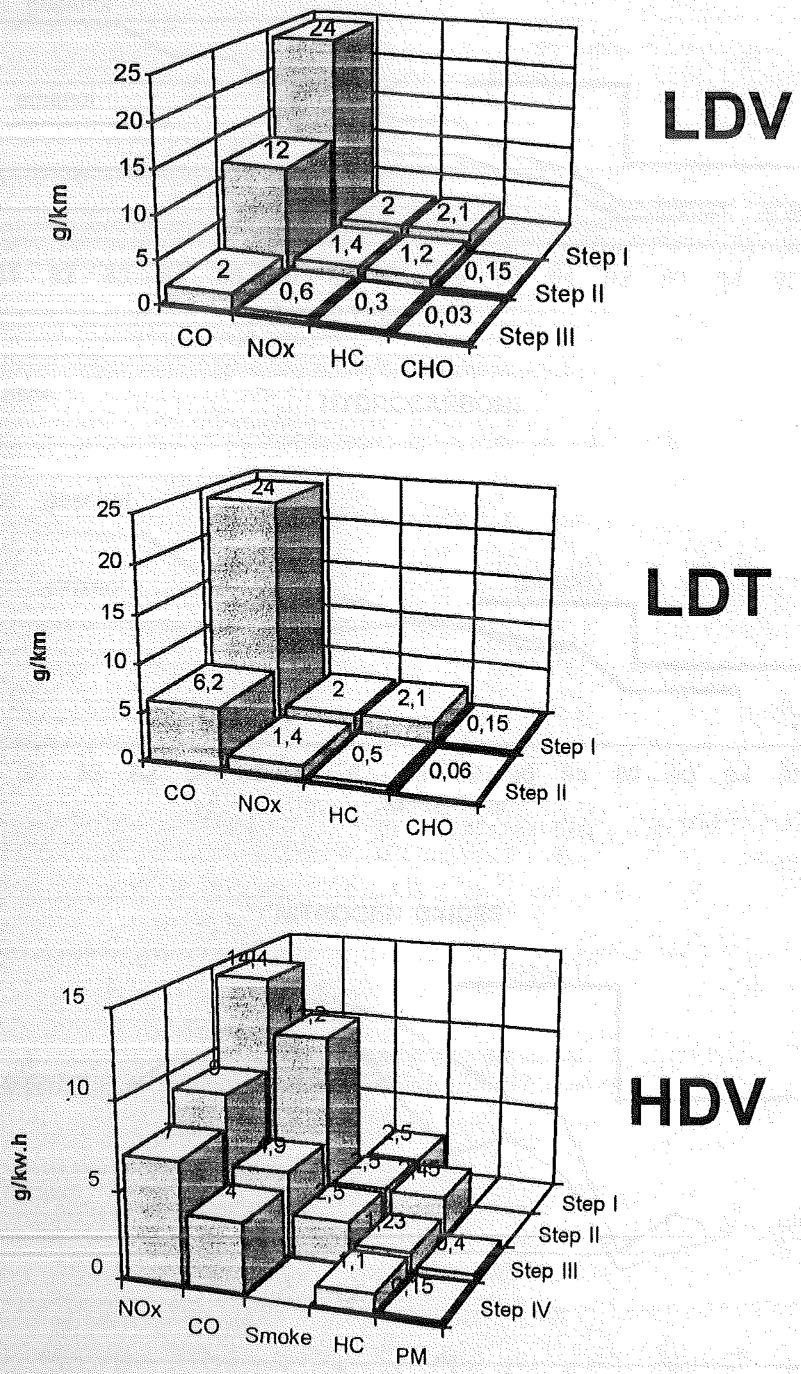


Figure 10 - New Vehicles Average Emissions

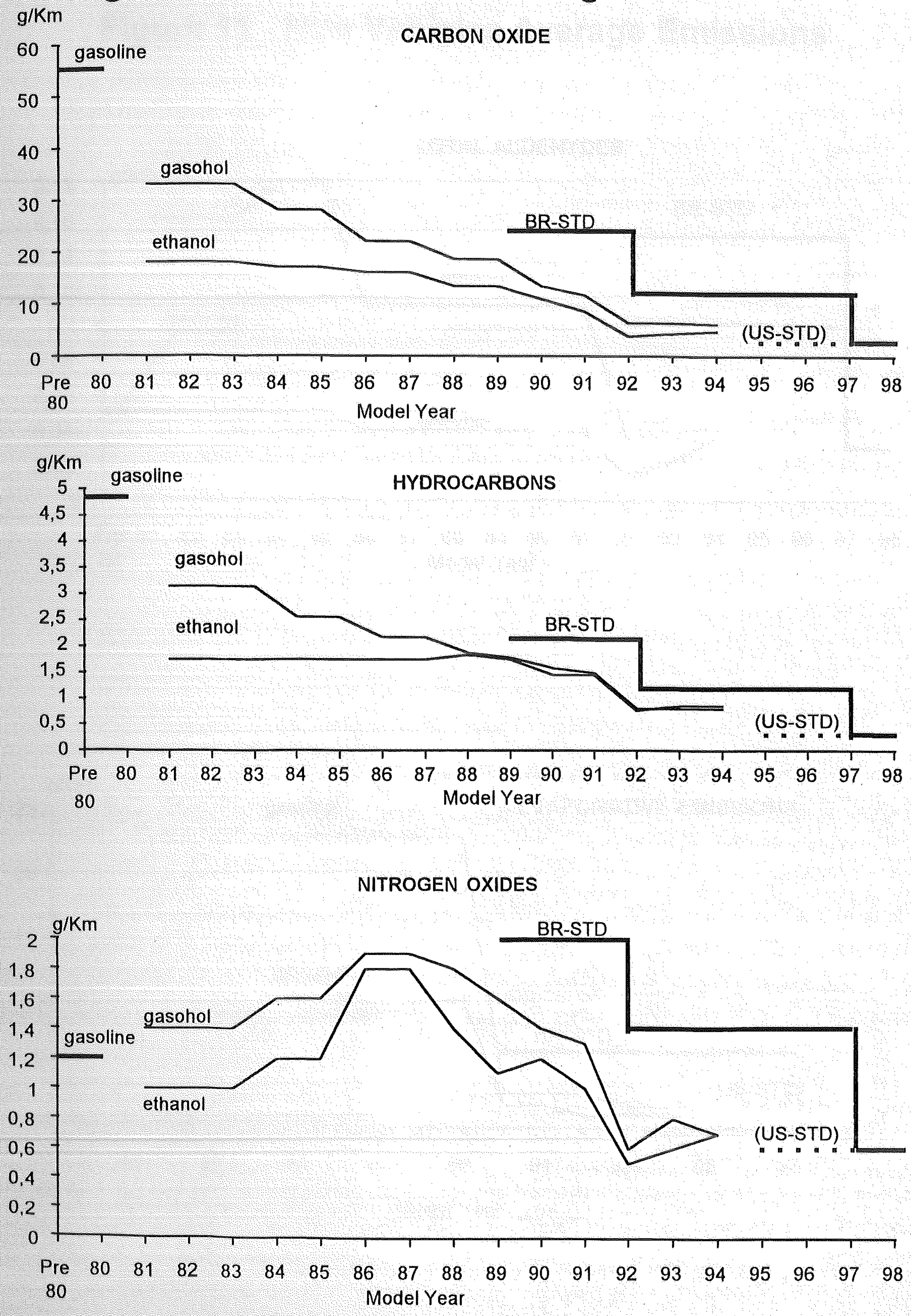
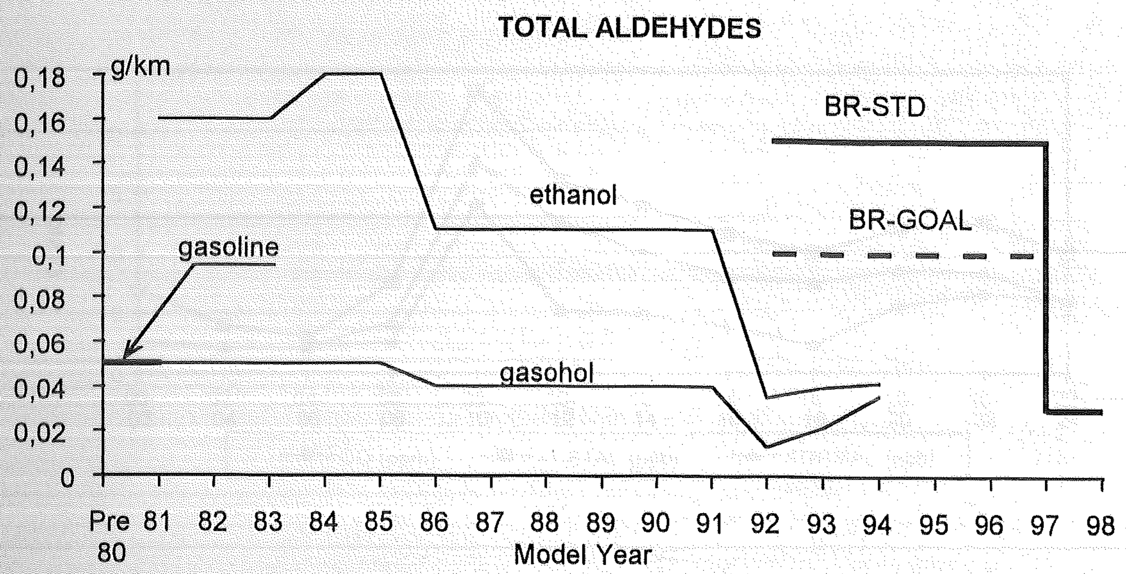


Figure 11 - New Vehicles Average Emissions



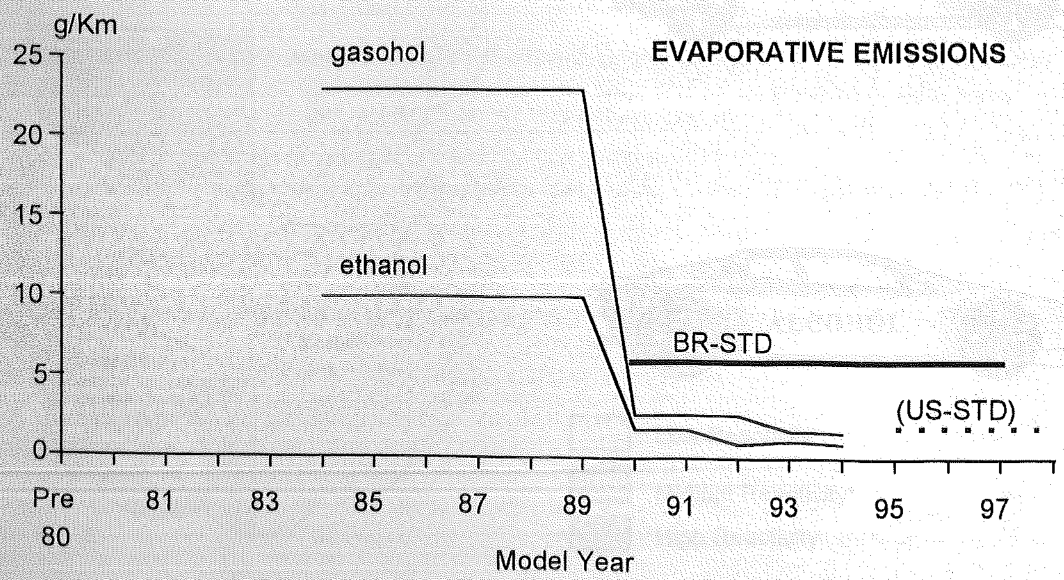


Figure 12 - Cerqueira César

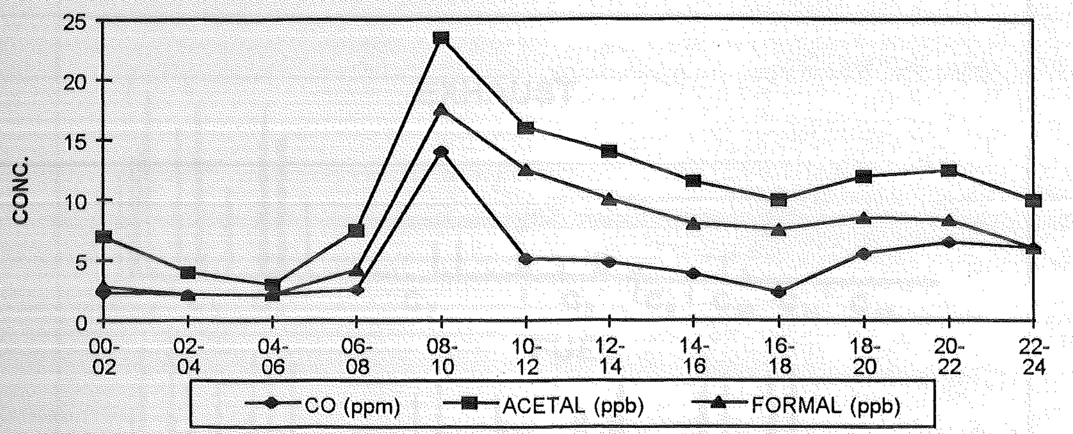
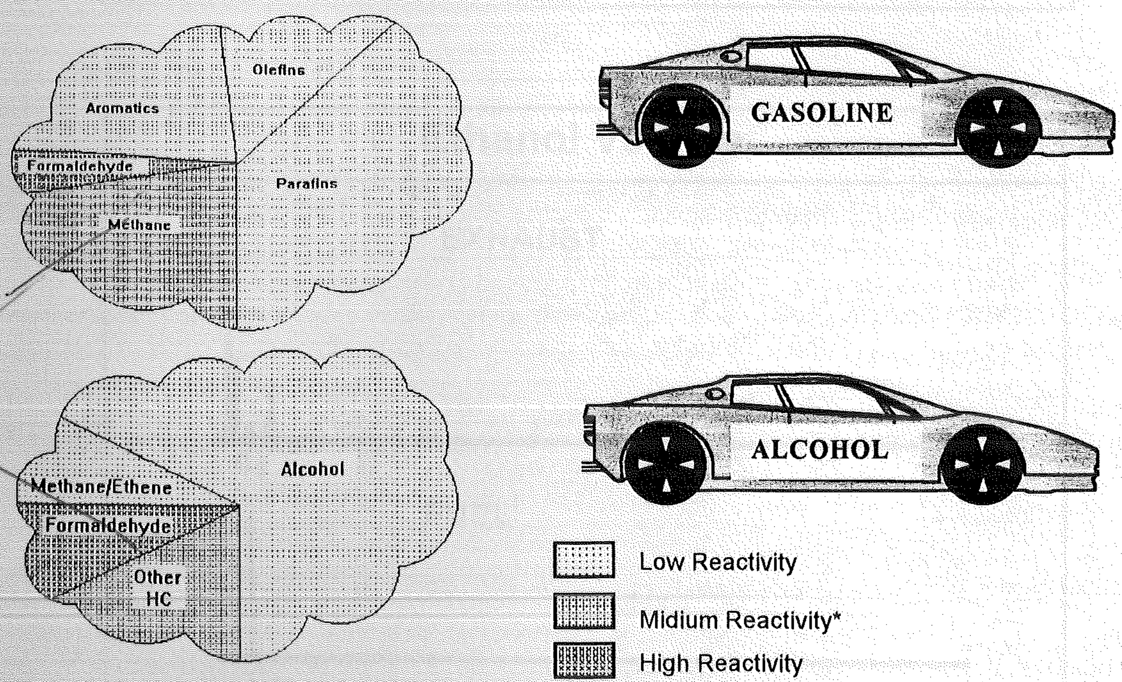


Figure 13 - Comparative Gasoline Emissions



Source: ref. 3

* Individual chemical species of these groups have range of reactivity from low to high

Figure 14 - Hydrocarbon Emissions

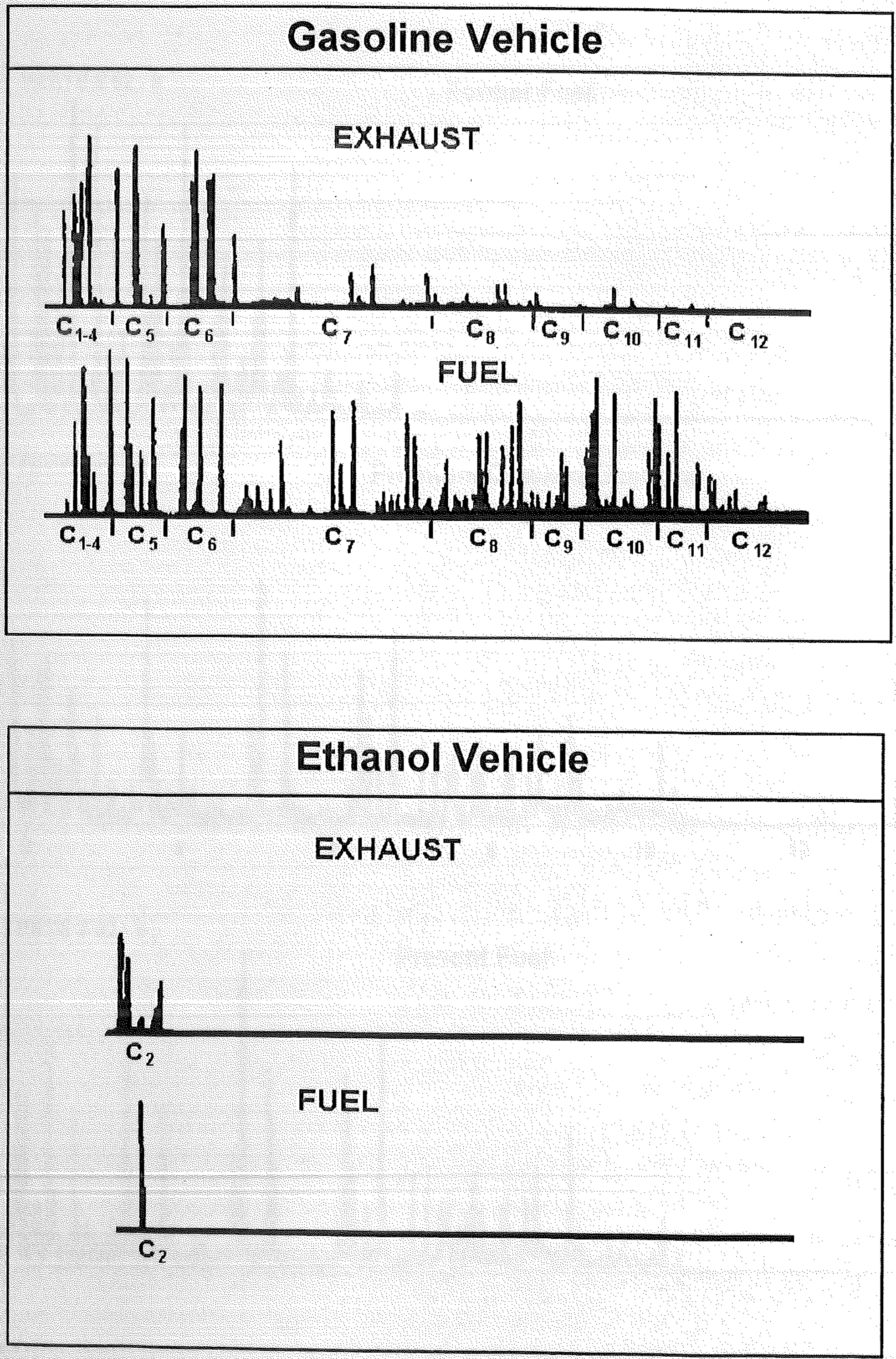
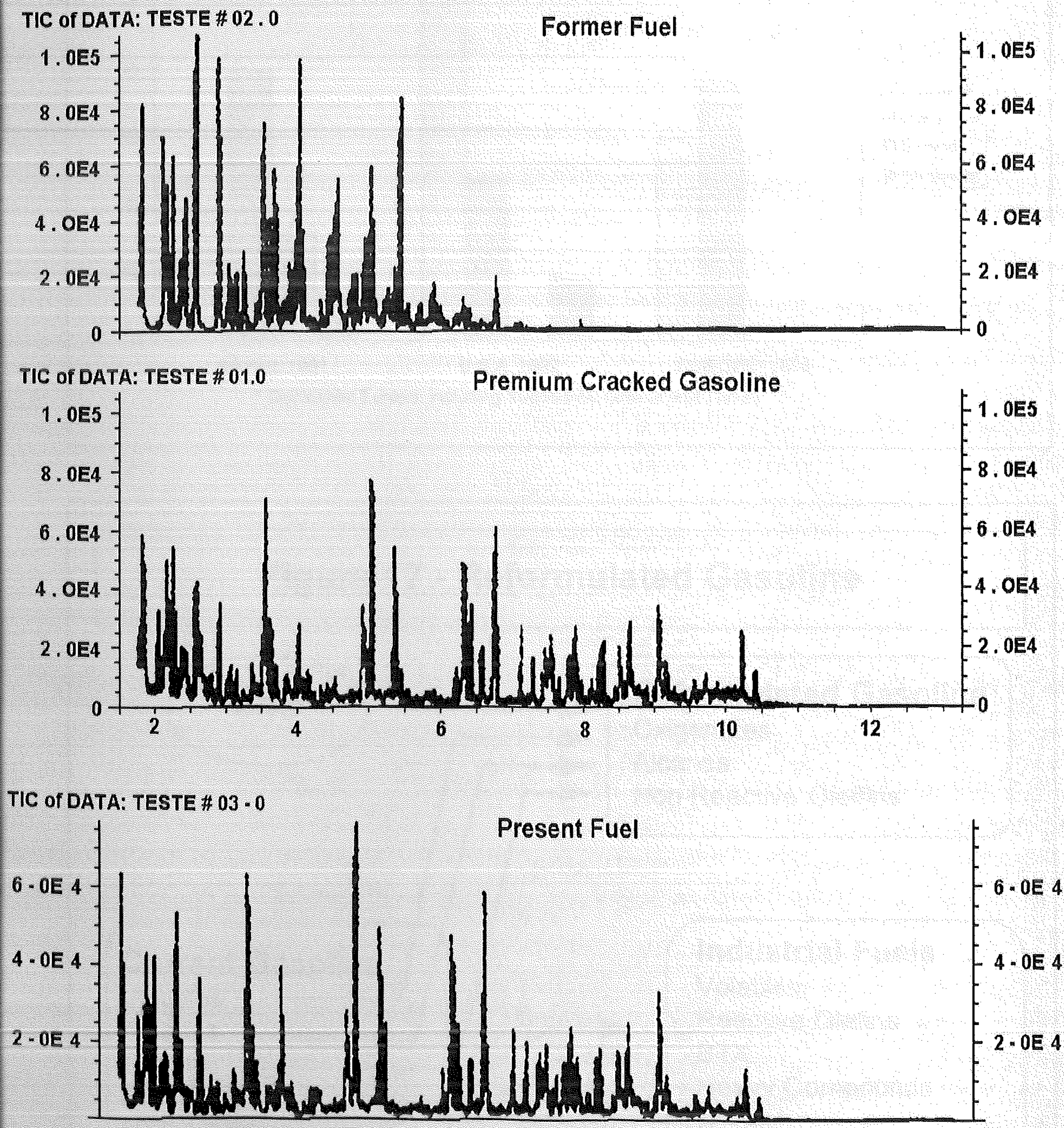


Figure 15 - Brazilian Gasoline Chromatograms



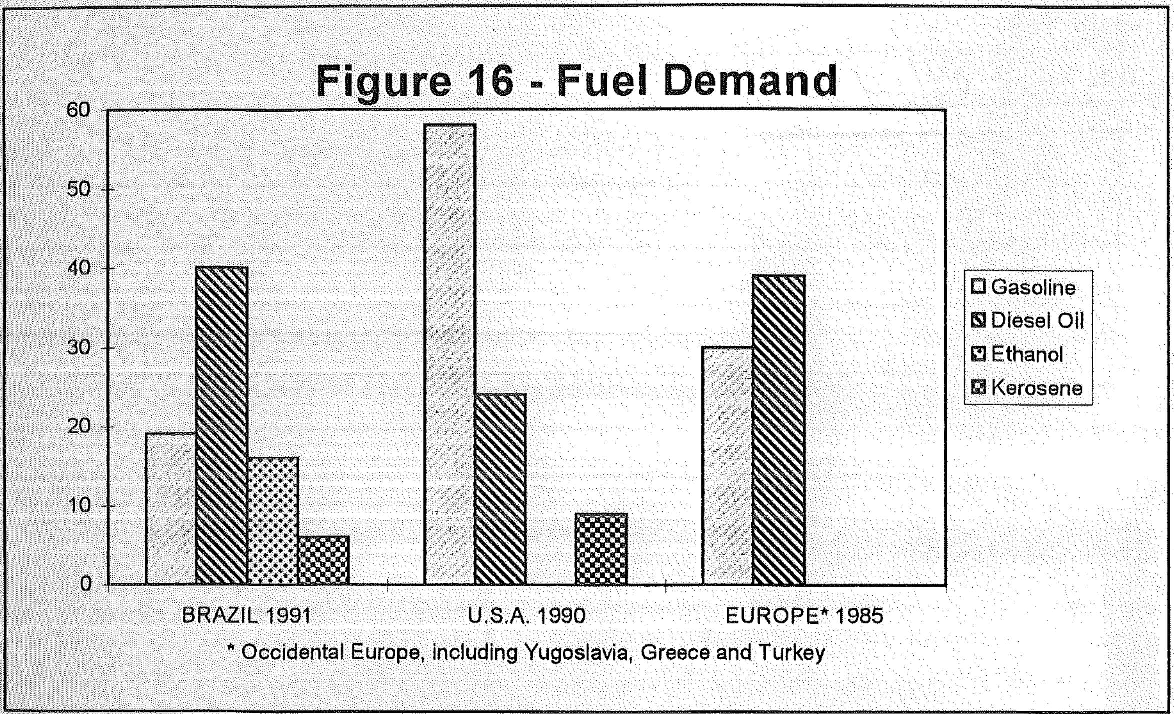


Figure 16 - Fuel Demand
60
50
40
30
20
10
0
Gasoline
Diesel Oil
Ethanol
Kerosene
BRAZIL 1991
U.S.A. 1990
EUROPE* 1985
* Occidental Europe, including Yugoslavia, Greece and Turkey

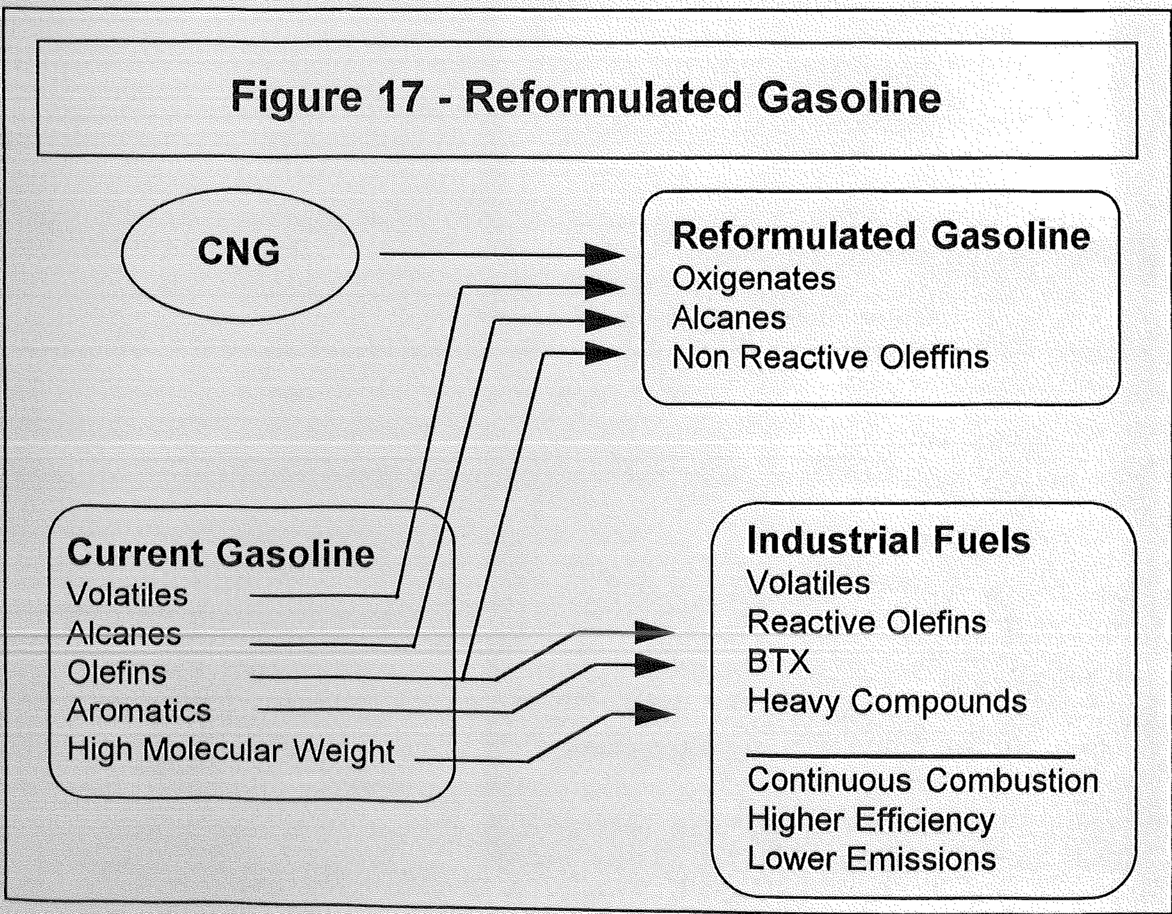


Figure 17 - Reformulated Gasoline
CNG
Reformulated Gasoline
Oxigenates
Alcanes
Non Reactive Oleffins
Current Gasoline
Volatiles
Alcanes
Olefins
Aromatics
High Molecular Weight
Industrial Fuels
Volatiles
Reactive Olefins
BTX
Heavy Compounds
Continuous Combustion
Higher Efficiency
Lower Emissions