OXFORD INSTITUTE FOR ENERGY STUDIES

A Comparison of the US and European Auto/Oil Programmes

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EV23

1997

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Oxford Institute for Energy Studies
Registered Charity, No. 286084

ISBN 1 901795 01 2

ABSTRACT

The US and European Auto/Oil Programmes were designed to help improve air quality by providing further knowledge (and advising regulators) about the relationships between fuels, engine technology, vehicle emissions and urban air quality. Through testing and air quality modelling studies they demonstrated some of the potential improvements due to vehicle technology and fuel (especially gasoline) reformulation.

The US Air Quality Improvement Research Program (AQIRP) was initiated in 1989 and was the first large-scale project to involve the environmental self-regulation and collaboration of two major industries, the automotive and oil industries (with a coordinating body). The European Auto/Oil Programme was inspired by the US Program, it had a similar framework but several important differences.

This paper compares the two programmes and considers the differences and similarities in the fuels and vehicles tested, the emissions measured, the methods and the results. It examines the major motivating factors behind these choices; these include contrasting air qualities and problems, environmental priorities, influences behind the programmes, legal histories and existing fuel and vehicle situations.

CONTENTS

1. INTRODUCTION

Urban air pollution caused by road transport emissions has become a major health threat to cities all over the world, and an increasingly significant problem in the developed countries following the clean-up of heavy industry and the move to less polluting industries. The ever increasing number of vehicles on the roads has partially cancelled any earlier improvements in vehicle technology and fuels and mobile sources are now the single largest contributor to ozone formation – and in 1990 produced over 90 per cent of urban carbon monoxide.[1] Although both Europe and the United States have extensive legislation attempting to control vehicle emission, in the past these have been based predominately on political decisions, not hard scientific fact.

Over recent years there have been two major programmes (the US and the European Auto/Oil Programmes) designed to help improve air quality by providing the information required to allow legislators and regulators to make informed scientific decisions concerning road transport emissions. The research programmes attempted to determine the effect that altering fuel parameters and vehicle technology has on air quality, through extensive vehicle emission tests and modelling future air quality. They also assessed the costs of altering the parameters or improving air quality, as incremental costs of changing the parameters (as in the US Program) or as cost-effectiveness in terms of impact on the main pollutants (European).

Both Auto/Oil programmes were large-scale collaborations between the automotive manufacturers and oil companies with a coordinating body, and used a innovative self-regulatory approach to environmental control.

The framework of the European Auto/Oil Programme was similar to that of the USA but there were significant distinctions between them. This paper looks at those differences and the reasons behind them. Items of focus include fuel parameters, vehicles tested and the pollutants of priority to the two regions. The contrasting air quality problems in the two regions seem to be a major influence, as the problems considered by the USA are more immediate, requiring immediate solutions and ignoring long-term considerations. The legislative and regulatory history of the two regions is also

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[1] *Senate Report No 101-228,* 'Clean Air Act, Amendments', 27 October 1990, p.83.

important as the United States is attempting to tackle its worst polluted areas, whereas the Europeans are attempting to introduce a single blanket solution to all its member states, to preserve the European single market. This complicates the situation as there is a substantial range of air quality in large European urban areas.

The paper starts with a discussion of the US air policy, considering some of the important pollutants and problems, such as pollution transportation, and historic approaches to emission control. Using this as a background, some of the motivations behind the objective and choices are explained in a summary of the US Auto/Oil Program. This is followed by a review of the variety in European air quality, the background legislation to the European programme and a synopsis of it, comparing the causes and consequences behind the differences and similarities of the two programmes.

2. US AUTO/OIL PROGRAM

Air Quality Legislation in the USA

Urban air pollution first became an acknowledged health threat in the United States in the 1950s, following several periods of excessive numbers of pollution related deaths. Initially only industrial pollution was considered but this is now under extensive controls and transport pollution is taking centre stage in the fight for clean air.

The first federal US air pollution law was passed in 1955 and was the basis for the Clean Air Act of 1963 (and Amendments of 1970, 1977 and 1990). Legislation was first implemented on road transport in 1965,[2] and has become increasingly stringent to try to keep up with the rapid increase in the number and use of vehicles.

So far, the legislative attempts to solve the United States' air quality problems have only been partially successful (even the US Senate admits that their attempts to control transport emissions up to 1990 did not entirely succeed[3]). They failed for a number of reasons; those of interest to this paper include inadequate understanding of the air quality mechanisms, the use of purely localized measures and no consideration of long-range pollution transportation (which is now perceived as extremely important to ozone and other pollutants).

The latest Clean Air Act Amendments (1990) attempted to take a broader geographical view of pollution legislation and include the pollution transportation effect. The Reformulated Gasoline Plan[4] was introduced to tackle air quality problems in the worst affected areas of the USA.

The Reformulated Gasoline Plan was designed to improve air quality by lowering emissions through fuel modifications. Since the effect of gasoline composition on emissions and air quality was not fully understood at the time, the government set performance targets rather than absolute specifications. They stipulated requirements of

♦ 15 per cent less volatile organic compound emissions

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[2]Murley, L. (ed.), *Clean Air Around the World: National Approaches to Air Pollution Control*, International Union of Air Pollution and Environmental Protection Associations, Brighton, 1995, p.368.

[3] *Senate Report No 101-228*, `Clean Air Act, Amendments,' 27 October 1990, p.3.

[4]*House Conference Report No 101-952*, 'Clean Air Act, Amendments' 26 October 1990, p.98.

♦15 per cent less toxic air pollutant emissions (defined as benzene, 1,3-butadiene, polycyclic organic matter, acetaldehyde and formaldehyde[5])

♦ no increase in emissions of the oxides of nitrogen

as compared to a specified baseline gasoline.[6] The auto and oil industries voluntarily initiated the Air Quality Improvement Research Program (AQIRP, more commonly known as the US Auto/Oil Program) to help find ways of achieving the necessary reductions.

The USA was divided into Areas in the 1970 Clean Air Act to aid pollution control, each area was classified as either Attainment or Non-Attainment (with extent of non-attainment) depending on the number of violations of the National Ambient Air Quality Standards (NAAQS). The 1990 Amendments redefined and enlarged some of the Areas to give a better representation of the air quality. An Area is now also Non-Attainment if emissions from within it contribute to a neighbouring Area's violation of the NAAQS. In the northeast United States the pollution transportation effect is so severe that the whole region has been declared an Ozone Transportation Region, and all ozone forming emission sources must now undergo the strictest controls, regardless of local pollution levels. Currently, about half of the Areas are Non-Attainment for either ozone or carbon monoxide (encompassing over 150 million people[7]).

All 'serious' and 'extreme' Non-Attainment Areas are required to join the Reformulated Gasoline Plan, and other areas have the option to join.[8] This accounts for between 22 and 55 per cent of US gasoline consumption, depending on the number of Areas that voluntarily join.[9] These reformulations were to be implemented within one year of the enactment of the Clean Air Act Amendments 1990. Reformulated gasoline should reduce ozone forming volatile organic compounds and toxic air pollutants emissions, due to a higher concentration of oxygenates and a lower concentration of aromatic hydrocarbons in the fuel.

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[5] ibid., p.104.

[6] ibid., pp.98–100. The baseline gasoline composition was specified on p.103, as there are significant compositional variations across the USA, due to differences in supply and requirements.

[7] *Senate Report No 101-228*, 'Clean Air Act, Amendments' 27 October 1990, p.82.

[8] *House Conference Report No 101-952*, 'Clean Air Act, Amendments' 26 October 1990, p.98 & p.101.

[9] This uncertainty in the amount of reformulated gasoline required is causing immense problems in the oil companies concerning the size of their refinery adaptions.

The Clean Air Act Amendments also restricted the use of some compounds, which reduced the compositional options for achieving these reductions (including maximum contents of 1 per cent benzene, 25 per cent aromatic hydrocarbons and a minimum oxygen content of 2 per cent). This move was criticized by the oil companies as it added cost and complications to the reformulation processes.

Other Factors behind the Program

The automotive and oil companies were under increasing pressure from strict EPA regulations on gasoline and vehicle emission controls (the USA, especially California, has a worldwide reputation for using tough air quality standards and regulations), so this programme was an opportunity to help find a more logical and cost-effective solution.

US environmental regulation has, in the past, been overturned and reversed. This has serious consequences for the relevant parties, especially in terms of lost investment and long-term planning. This may be discouraged by providing a sound scientific basis for the legislation, which should cushion implemented regulation from some of the more fickle influences of politics.

The oil industry may have joined the Program as a negotiation tool, agreeing to provide the required information on the potential of transport fuels in return for federal support and a realistically achievable timetable for implementing the necessary modifications for fuel reformulation. They believed the EPA was threatening to back alternative fuels if they did not cooperate or failed to meet the reformulated targets.[10] The oil industries were also coming under stress from the influential biofuels lobby and an increasingly environmentally aware public (thus losing support from their traditional allies in the government through public pressure).

The motivations of the automotive industry in joining the Program were less obvious than those of the oil industry, as it did not consider vehicle technology or quality and therefore the industry had nothing to lose or gain from participating. However, as the industry believed it had been excessively focused on in the past as the main culprit for transport emissions, it had undertaken a great deal of research into reducing emissions using vehicle technology but felt that progress was beginning to be impeded by the nature of the US fuels. It believed that research was needed into the contributions the fuels could make to reduce emissions as further reductions from vehicle technology

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[10]McArragher, J. S. 'The US Auto/Oil Programme and its Relevance to Europe' in Commission of the European Communities, *European Symposium "Auto Emissions 2000", "Stage 2000" of the European Regulations on Air Polluting Emissions of Motor Vehicles, Proceedings of the Symposium,* Office for Official Publication of the European Communities, Luxembourg 1993, p.207.

were becoming smaller and considerably more expensive. They also thought there was potential in a more holistic approach which considered the reductions that could be made when the two industries cooperated.

Under these direct and indirect pressures, the oil and auto industries decided to embark on a three-year research project into the emission reductions that could be made using reformulated gasoline, giving estimates of the costs of such reformulations, in order to provide guidance for future legislative decisions. This was the US Auto/Oil Program.

The Program

The US Auto/Oil Program was designed to find options for improving air quality problems due to road transport. It was more formally known as the Air Quality Improvement Research Program (AQIRP) but gained its working title as it was run by three US automotive manufacturers[11] and fourteen domestic oil companies[12] (and the Coordinating Research Council, which encourages collaborative research between the two industries). Its objectives were to 'develop data on potential improvements in vehicle emissions and air quality – primarily ozone – from reformulated gasoline, various other alternative fuels and developments in vehicle technology'.[13]

The Program was run between 1989 and 1993 and was actually Phase I of AQIRP, which has now concluded with the completion of its second stage. Phase I rather than the entire venture is of interest to us as it was the first of its kind, and the example upon which other programmes have been based (most notably the European Auto/Oil Programme).

The Auto/Oil Program also consulted various governmental and state bodies, such as the Environmental Protection Agency (EPA), the California Air Resources Board (CARB) and the US Department of Energy (DOE), but interestingly no environmental groups or other vested interests. The participants argued that they were trying to advise legislators, not solve the issue, so the legislative viewpoint was the only one considered. There were also problems in consulting environmental groups due to their large number and the lack of consensus among them.

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[11]The auto manufacturers involved were Chrysler, Ford and General Motors.

[12]The oil companies were Amoco, ARCO, Ashland, BP America, Chevron, Conoco, Exxon, Marathon, Mobil, Phillips, Shell, Sun, Texaco and Unocal. There were also three associate members, Elf France, Ethyl Corp. and UOP.

[13]Burns, V. et al., 'Description of Auto/Oil Air Quality Improvement Research Program,' in *Auto/Oil Air Quality Improvement Research Program,* SP-920 SAE, Warrendale, 1992, p.2

However, experts in several fields were consulted, through a Distinguished Advisory Panel, which consisted of technical experts independent of either industry, who oversaw the Program and attempted to ensure objectivity at every stage from planning to execution. These people were felt to be critical to the acceptance of the results and therefore success of the Program.

AQIRP Phase I cost the automotive and oil industries $15 million, which was split equally between them, despite therebeing substantially more oil companies than auto. Its solutions required a substantial amount of investment and increase in manufacturing costs on the part of the US oil industry but provided data to calculate the most cost-effective solutions for individual air quality problems.

AQIRP employed a three-pronged approach to achieve its objectives. The first involved an inter-industry research project, which tested various fuel compositions on a representative sample of the current US fleet to determine the synergetic relationships between the vehicle technology, fuel parameters and emissions and hence to find immediate options for improvement. The second, an air quality modelling study, assessed the potential of these options to translate specific reductions in emissions into improvements in air quality, by predicting future air quality in a range of the worst affected cities in the USA. The final component, a cost study, assessed the incremental costs of the possible gasoline (and methanol) composition. I will discuss each section in turn.

Inter-industry Research Project

The practical research project was designed to help quantify the complex relationships between fuel composition, vehicle technology, emissions and air quality. It was conducted in the companies' laboratories across the USA between October 1989 and December 1990, and consisted of over two thousand tests run on different fuels and vehicles.

The US Auto/Oil Program needed to find options that would immediately reduce vehicle emissions, and the most effective way to achieve this was by optimizing fuel quality in the current vehicle fleet. Therefore the gasoline test fleet was designed to represent the current (to 1989) vehicle mix on the American roads, using two sets of gasoline vehicles, a current batch (1989 models) and a group of older vehicles (1983–5 models). These older vehicles were subsequently dropped when they were recognized to be obsolete in terms of the in-use fleet (however they were used in several of the Phase II investigations into high-emitting vehicles).

The Program tried to examine the fuel/emission relationships systematically, by testing 29 gasolines, each of which differed from the next by the level of just one parameter. The final test fuel matrices also allowed investigation of interdependent effects between certain parameters.

AQIRP also included a study using gasoline/methanol mixes in variable and flexible fuelled cars. This paper will be looking at the gasoline section in more detail as it formed the largest part of the programme and is common to both the European and US programmes. Other variables are listed in Table 2.1.

Table 2. 1: Variables in the US Auto/Oil Program

Fuels:	Gasoline Gasoline/methanol mixes
Parameters varied:	Aromatics, T90, olefins, MTBE, RVP, ETBE, ethanol and sulphur levels in gasoline methanol in flexible/variable fuelled engines
Pollutants tested:	Nitrogen oxides, carbon monoxide, volatile organic compounds, benzene, 1,3-butadiene, formaldehyde, acetaldehyde fuel economy
Vehicles:	current (1989) older (1983-5) flexible and variable fuelled vehicles
Emissions tested:	Exhaust emissions (engine out and tailpipe) evaporative and running loss emissions

Fuel. Gasoline is the major fuel in road transport in the USA. It was focused on by the Clean Air Act Amendments (1990) as gasoline reformulation has the largest potential for immediate reductions in vehicle emissions and can therefore improve current air quality.

Methanol/gasoline mixes also have potential for providing improvement in emissions, although this would not be as substantial or immediate, due to the low number and very slow increase of flexible and variable fuelled vehicles on the US roads. However, methanol/gasoline mixes hold many advantages over pure gasoline in terms of mitigating vehicle emissions; especially in reductions in nitrogen oxides, toxic air pollutants and to a lesser extent, potential ozone-formation.[14]

At first glance there is confusion as to why the petroleum industry agreed to test methanol mix fuels alongside gasoline, as any promotion of fuels which they do not market will increase their competition. However, they were under a lot of pressure from the automotive companies, many of whom are developing flexible and variable fuelled vehicles, and from the government, the biofuels lobby and the general public (who in general hold a very negative impression of the oil industry). They felt that in order for the programme's results to be taken seriously, the objectives had to be seen to be fair and not manipulated to fit the participants' wishes. They may also have hoped the research might disprove methanol's reputation as a commercially viable 'green' fuel. These reasons led to the inclusion in AQIRP of two methanol/gasoline blends (10 and 85 per cent methanol) tested in nineteen different flexible/variable fuelled vehicles.

Gasoline Parameters. The US Auto/Oil Programme varied a number of gasoline parameters both independently and in combination, looking at interdependent effects. It selected parameters through a review of prior work on emissions from gasoline engines (although it had to work within the compositional limitations of the Clean Air Act Amendments of 1990). Previous work included studies investigating compositional change and vehicle technology on emissions, but these were either out of date or not specific enough to determine the exact cause or impact of individual changes. However these studies indicated which parameters had the most potential to affect emissions and therefore the parameters for investigation in AQIRP.

It also examined interdependent effects between combinations of parameters – not all interdependent effects could be tested due to the limited budget and time constraints. The individual parameters and combinations were chosen through negotiation by the participants, with the highest priority going to the most important in terms of required knowledge and estimated emission reducing potential and to maximize the useful information available from the test data. These parameters were then assembled in three gasoline matrices varying general composition, oxygenate content and sulphur concentrations. These can be seen in Table 2.2.

AQIRP blended a total of 29 gasolines with every combination of high and low levels of each

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[14] Faiz, A. Et al., *Air Pollution from Motor Vehicles*, The World Bank, 1996, pp. 203-4.

parameter within a matrix. This allowed the tests to determine the effects of individual parameters on emissions and some interdependent effects, as each of the test fuels differed from the others by the level of just one parameter. The high/low framework meant that no assessment of the relationships' linearity could be made. This problem was addressed in Phase II of AQIRP, when fuels with incremental changes in sulphur were tested. This showed that many of the relationships were indeed non-linear, including those of HC, NMHC, CO, benzene, formaldehyde, and the impact of sulphur.

The test fuels were mostly unlike any real current or potential gasolines, with unusually high or low levels of each parameter. However they were blended from existing industrial refinery streams, to assess the potential of the available resources.

Gasoline Pollutants. The US Auto/Oil Program was prompted by the Reformulated Gasoline Act in the Clean Air Act Amendments of 1990. These stipulated a 15 per cent reduction in emissions of VOCs (volatile organic compounds, a precursor of ozone) and toxic air pollutants (benzene, 1,3-butadiene, polycyclic organic matter (POM), acetaldehyde and formaldehyde[15]) and no increase in nitrogen oxide emissions (NO_x). These pollutants (except POM) were then measured in the US Auto/Oil Program, with carbon monoxide and fuel economy (to determine absolute reductions in the pollutants and negative effects of the varied parameters). POM was excluded as measurement techniques for gasoline POM were considered to be unsatisfactory at the time.[16]

The category of volatile organic compounds consists of hundreds of different species, with a large range of individual properties and differing relationships with fuel composition and technology. Changes in fuel formulation alter the distribution of volatile organic compounds and therefore their impact on emissions and ozone formation. This is also true for the toxic air pollutants, which react differently to changes in fuel composition.

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[15]Toxic air pollutants were defined in the Clean Air Act Amendments of 1990. *House Conference Report No 101-952*, 'Clean Air Act, Amendments' 26 October 1990, p.104.

[16]Gorse R.A. et al, 'Toxic Air Pollutant Vehicle Exhaust Emissions with Reformulated Gasoline,' in *Auto/Oil Air Quality Improvement Research Program*, SP-920, SAE, Warrendale, 1993, p.120.

Table 2.2:

The Test Fuel Matrices from the US Auto/Oil Program

Test Matrix A

Compositional Fuel Variable Target Levels

	Factorial Design		Industry Average
	Low	High	
Aromatics, %	20	45	32
MTBE, %	0	15	0
Olefins, %	5	20	12
T_{90}, °F	280-300	350-360	350-360

Sixteen fuels with an Industry Average and an Emission Certification Gasoline, named AMot, amOT, etc. where A/a = high/low Aromatic content, M/m = high/low MTBE, O/o = high/low olefin content, T/t = high/low T90 level

Test Matrix B

RVP/Oxygenates Fuel Variable Target Levels

	Factorial Design	
	Low	High
RVP, psi	8	9
Ethanol, vol %	0	10
ETBE, vol %	0	17
MTBE, vol %	0	15

Eight fuels based on fuels A (the industrial average gasoline) and 'amot' (low aromatics, MTBE, olefins and T_{90}) fuel F from Matrix A.

Test Matrix D

Sulphur Fuel Variable Target Levels

	Factorial Design		Emission Certification Fuel
	Low	High	
Sulphur, ppm	50	500	119

Three fuels based on the Emission Certification fuel (fuel B from Fuel Matrix A)

Source: Auto/Oil Air Quality Improvement Research Program, SAE-920.

All the pollutants considered in the US research project have been investigated before; however it has become clear over recent years that other less apparent pollutants are equally or possibly more damaging as these traditional gasoline pollutants. These include particulate matter (PM_{10} [17]), which was excluded from the US Auto/Oil Program as, although it has long been an acknowledged danger from stationary sources and diesel cars and trucks, it has only recently been seen as an important pollutant from the gasoline engine.

Vehicles. The US Auto/Oil Program was designed to find the immediate options for mitigating air quality problems through the use of reformulated gasoline. This short-term improvement must be achieved by optimizing the fuel within the existing vehicle fleet; therefore the gasoline vehicles tested in the Auto/Oil Program were meant to be representative of the 1989 in-use fleet.

They started gasoline testing with two blocks of used vehicles, which represented the range of vehicle and engine technology in use (although all had oxidation or 3-way catalysts[18]). The first was a selection of ten 'current' (1989) models and seven 'old' models (from 1983 to1985); each one was repeated, making a total of 34 vehicles. However the members of AQIRP failed to realize how obsolete the older vehicles would be by the time the Program's results were presented so the older vehicles were dropped from the test fleet during the research project (after Fuel Matrix A).

The Auto/Oil Program also tested three prototype variable and flexible fuelled vehicles, which were tested with the fuels from Matrix C (methanol/gasoline mixes).

Tests. The emission tests involved running each combination of fuel and engine through a standard driving cycle to determine exhaust emissions (tailpipe and engine-out) and evaporative emissions. See Diagram 1 for the FTP-75 test cycle and the AQIRP gasoline test procedure.

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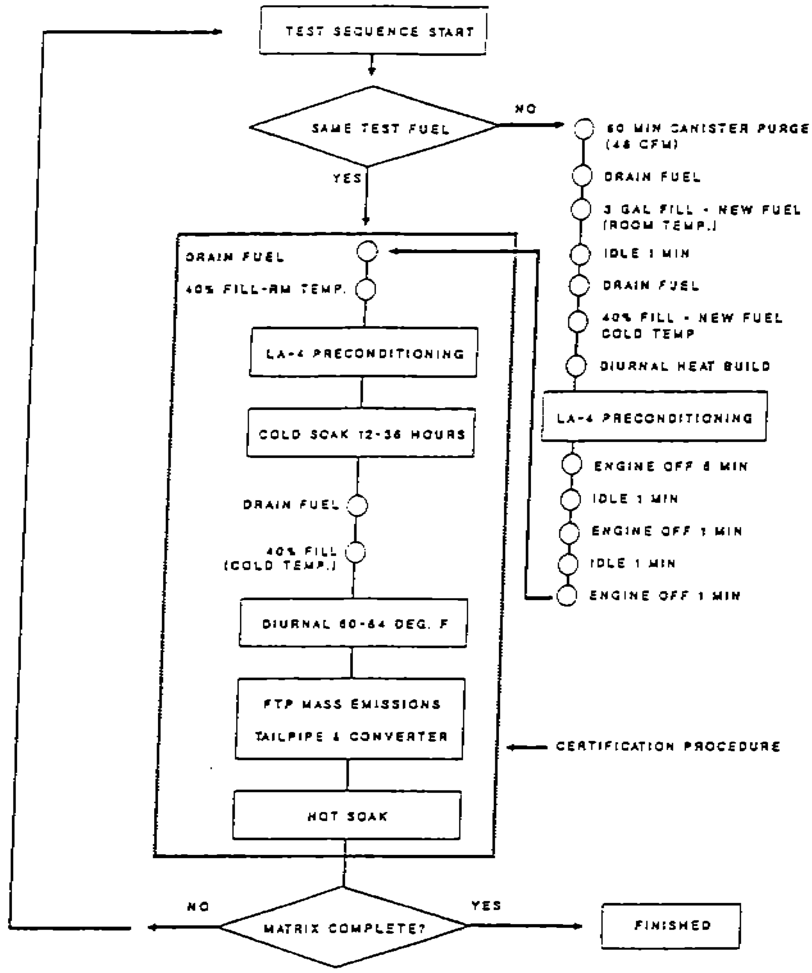
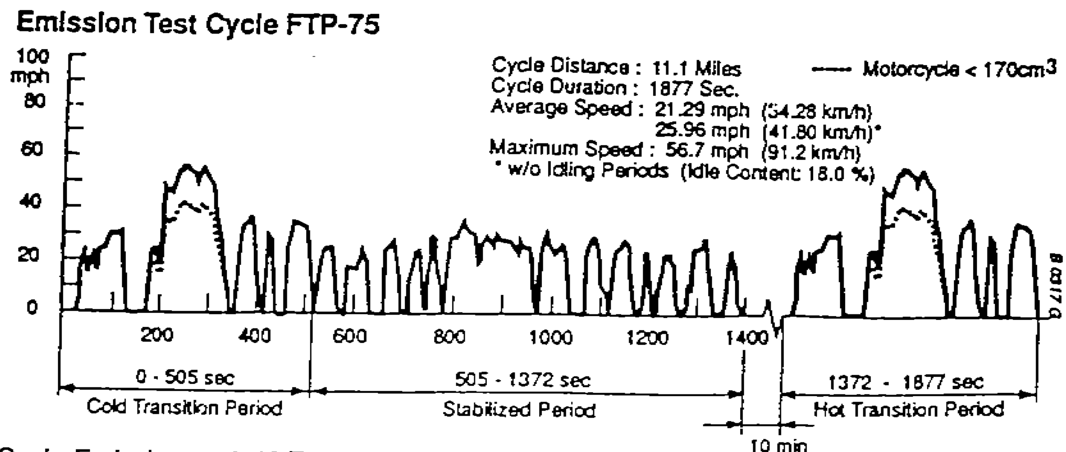
[17] PM_{10} is defined as particulate matter less than ten microns in aerodynamic diameter. Since the US Auto/Oil Program it has become obvious that particulate matter less than 2.5 microns across has the potential to be even more damaging as it can enter the alveoli of the lung and cause serious respiratory damage.

[18] Catalytic converters can reduce exhaust emissions by up to 99 per cent; however the catalysts are extremely sensitive to temperature and do not function at low temperatures. The catalysts can reach the temperature for optimal efficiency after travelling approximately 1 km, although this is significantly increased by cooler ambient temperatures. In some cars the vehicle produces the same mass of volatile organic compounds and carbon monoxide emissions during this km, as it would produce travelling 375 km with a hot catalyst. However there is a wide range of catalyst efficiencies and light-off times between vehicles. Catalysts are also affected by high sulphur levels in the fuel, as this 'poisons' the catalyst by binding to the precious metals within.

Diagram 1 The US Gasoline Vehicle Test Procedure and FTP-75 Driving Cycle





Cycle Emissions = 0.43 TP_{cold} + SP + 0.57 TP_{hot}

Sources: Hochhauser, A.M. et al, 'The Effects of Aromatics, MTBE, Olefins and T90 on Mass Exhaust Emissions from Current and Older Vehicles,' in *Auto/Oil Air Quality Improvement Research Program*, SAE-920, Warrendale, 1992, p.90 and *Motor Vehicle Emission Regulations and Fuel Specifications - 1992 Update*, CONCAWE, Brussels, 1992, p.95.

The vehicles were preconditioned to minimize carry-over from the previous fuel, and run through the transient FTP-75 (Federal Test Procedure)[19] driving cycle on a chassis-dynamometer. The FTP-75 cycle is the standard US regulation test cycle for light duty vehicles (LDVs) It was based on driving patterns in Los Angeles[20] and is a modified version of the 1972 cycle. The driving habits of the American public have changed (as has the technology available for emission testing) since 1975 and the FTP-75 cycle is now estimated to fail to cover 15 per cent of all US driving.[21] Real driving has higher average and maximum speeds and accelerations, shorter average journey lengths, fewer hot catalyst starts and more 'enrichment events' (which occur during periods of extreme acceleration and can produce up to half the emissions of a cold start[22]). These factors will all lead to an underestimation of fleet emissions, although further work (in AQIRP Phase II) showed the distribution of the emission profile remains relatively unchanged. It also showed that, when using a higher speed and acceleration cycle, there was no substantial impact on overall reactivity[23] and therefore in a purely ozone study the FTP cycle's inadequacies were not severe.

The majority of transport pollution is emitted from the vehicle's exhaust. This is collected from the tailpipe and as engine-out emissions, which allows assessment of absolute exhaust emission levels and the impact of the various control technologies used (such as the catalytic converter). The pollutant concentrations are determined using standard analysis techniques. They also calculated the reactivity of the speciated hydrocarbon emissions (by considering the effect of 175 individual hydrocarbon species), which affects the ozone forming potential of the pollution.

The US Auto/Oil Program also tested evaporative (hot soak and diurnal losses and running

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[19]*Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines: Certification and Test Procedures,* 40 CFR 86, US Government Printing Office, Revised July 1, 1990. in existence on October 1, *1989* as quoted in CONCAWE, Motor Vehicle Regulations and Fuel Specifications – *1994 Update,* Brussels, 1994, p.124.

[20]CONCAWE, Motor Vehicle Regulations and Fuel Specifications – *1992 Update*, Brussels 1992, p.94.

[21]US EPA *Highway Vehicle Emission Estimates-II,* June 1995 & US EPA *Federal Test Procedure Review Project: Preliminary Technical Report* EPA 420-R-93-007 May 1993 as quoted in the *Auto/Oil - Air Quality Improvement Research Program Dynamometer Study of Off-Cycle Exhaust Emissions,* Technical Bulletin No.19, AQIRP, Coordinating Research Council, Atlanta, 1996, p.6.

[22] Calvert, J.G. et al, 'Achieving Acceptable Air Quality: Some Reflections on Controlling Vehicle Emissions,' *Science*, vol.261, no.5117, 2/7/93, p.40.

[23]*Auto/Oil - Air Quality Improvement Research Program Dynamometer Study of Off-Cycle Exhaust Emissions,* Technical Bulletin No.19, AQIRP, Coordinating Research Council, Atlanta, 1996.

losses[24]) emissions for some of the vehicles (these can account for up to 30 per cent of all urban volatile organic compounds emissions[25]). The effects on evaporative emissions were required to build an emission profile for each fuel for use in the air quality modelling study.

The diurnal and hot soak evaporative emissions were collected using the standard SHED method (Sealed Housing for Evaporative Determination). The running loss emissions were measured during vehicle operation at relevant points in the vehicle (using an emission point source method developed for AQIRP[26]). These were only analysed for VOCs, as any compound not present in the unburnt gasoline will be absent from the vapours. This also includes nitrogen oxides, carbon monoxide, 1,3-butadiene, formaldehyde and acetaldehyde.

Initially most of the fuels were modelled, with a small sample tested for validation. This showed that the models were inadequate, but by the time this was recognized, it was no longer possible under the Auto/Oil time constraints to test all the remaining fuels. As the evaporative emission data for each fuel is required for the air quality modelling study, five fuels were excluded from the study.

Results. The results from the AQIRP testing project are summarized in Table 2.3. The percentage reductions (and increases) are from the reformulated fuels compared to the base gasoline (fuel A). There was quite a range of impacts of the fuels, depending on the vehicle used, so the numbers displayed in Table 2.3 are the fleet averages for each fuel on the two fleets (where applicable).

As can be seen in Table 2.3, sulphur was the only parameter which reduced all four of the pollutant categories, and is therefore an excellent choice for immediate regulation. Its broad based reduction is due to its effect on the existing emission control technology, the catalytic converter, and is a mitigating effect rather than an absolute decrease in engine-out emissions. However, if vehicle emissions are to be reduced substantially further, then this is what must be focused on.

The Matrix A parameters were tested on both old and current (to 1989) vehicles, but on several occasions they gave contrasting results on the relationship between emissions and fuel

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[24]Refuelling and bulk storage evaporative emissions were not considered in AQIRP as there were already estimates available and they are relatively unimportant to the emission profile.

[25]*Senate Report No 101-228*, 'Clean Air Act, Amendments' 27 October 1990, p.96

[26]Burns V.R. et al., 'Effects of Gasoline Composition on Evaporative and Running Loss Emissions', in *Auto/Oil Air Quality Improvement Research Program,* SP-920, SAE, Warrendale, 1992, p.257.

parameters. In the case of T_{90} and aromatic content this may have been due to the differences in fuel systems but there was also a substantial range of emissions from different models with the same technology. This introduced uncertainty into the effects of gasoline reformulation, made it more difficult to define absolute scientific results, and damaged AQIRP's reputation for credibility.

The exhaust emission results from the US Auto/Oil Program are reliable and validated, although they produced different conclusions on the emission relationships for the two vehicle fleets. The results for evaporative emissions are considered only moderately reliable, and the running loss results were deemed unreliable.[27] This is true in general for all measurements of evaporative emissions, as they are far more sensitive to test conditions than exhaust emissions. The test conditions are much harder to control, and include the ambient, vehicle and vapour temperatures, which all have a significant impact on the evaporative emissions. Exhaust emission measurements are also less sensitive due to their magnitude, which means the relative impact of temperature variations are smaller.

Air Quality Modelling Study

The air quality modelling study predicted future levels of ozone in three US cities – Los Angeles, New York and Dallas-Fort Worth – in the years 2005 and 2010 to assess the best fuel composition options. It only considered fuel improvements as the US government was looking specifically for a short-term fuel solution. Vehicle modifications were considered in AQIRP Phase II, which had its own air quality study.

The study used the results from the inter-industry research program and the cities' historical air quality data to model future emissions and therefore ozone concentrations in the three cities. It used emission models to predict the composition of pollution in the future, considering not only transport emissions, but also stationary sources and biogenic emissions for each city. It then applied the compiled emission profiles to the individual air modelling analysis, testing all the fuels on a relatively simplistic model to identify the most promising, then applying a detailed analysis to these.

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[27]Chock D.P. et al, 'Reactivities and Ozone Impact of Emissions from Vehicles using Reformulated Gasolines and M85,' in *The Vehicle and the Environment, XXIV FISITA Congress 1992*, The Institute of Mechanical Engineers, London, 1992, p.107.

Table 2.3:

Summary of the Results of Research Project

Parameter varied	fleet	CO	NO_x	Toxics	Hydro-carbons	Fuel Economy
Aromatics 45→20%	**new**	↓ 13%	-	↓ 21%	↓ 14%	↓ 1-3%
	old	-	↓ 11%	↓ 23%	↑ 6%	
MTBE 0 → 15%	**new**	↓ 14%	a	-	↓ 5%	↓ 1-2%
	old	↓ 11%	a	-	↓ 9%	
Olefins 20 → 5%	**new**	-	↓ 6%	b	↑ 6%	↓ <0.5%
	old	-	↓ 6%	b	↑ 6%	
T_{90} 360 → 280°F	**new**	-	↑ 5%	↓ 16%	↓ 22% c	↓ 1.5%
	old	↑ 14%	-	-	↓ 6%	
Sulphur 450 → 50ppm		↓ 19%	↓ 8%	↓ 10%	↓ 18%	-
RVP 9 → 8psi	d	↓ 9%	-	-	↓ 4%	-
Methanol 0 → 85%		↓ 31%	↑ 23%	-	↓ 37% e	

\- = no significant effect

a = unaffected except when aromatic levels are low, when they are increased by 5 per cent

b = no net effect on toxics but 1,3-butadiene was reduced by 30 per cent

c = high aromatic content increased the impact of T_{90}, leading to a further reduction of volatile organic species emissions when T_{90} was decreased

d = reducing RVP reduced total evaporative emissions by 34 per cent

e = Organic Material Hydrocarbon Equivalent

Source: *Auto/Oil Air Quality Improvement Research Program, Phase I Final Report,* AQIRP, 1993

Only fuels from Matrix A were included in the Phase I air quality modelling study. Sulphur, ethanol and RVP fuel effects on ozone were modelled in Phase II. Fuels with varying sulphur levels were not tested in the US Auto/Oil Program Phase I air study, despite showing the broadest reductions in emissions. This was because the Phase I sulphur tests were only used to define a more thorough investigation in Phase II, and had taken no measurements of the specific organic compounds in the exhaust emissions and therefore had no estimate of reactivity (and impact on ozone formation).

Los Angeles, New York and Dallas-Fort Worth were selected because they all had air quality problems and reliable historical data. They were representative of the range of meteorological conditions and emission profiles existing in the USA due to their differing emission profiles, meteorological, topographic and social situations (see the section on US air quality).

The air study initially produced base emission models, by assuming that all vehicles will use the average industrial gasoline (fuel A in the Auto/Oil Program) and predicting changes in total emissions. The emission models considered stationary and biogenic source predictions as well as non-mobile, for they are fundamental in assessing the overall impact on air quality of a fuel modification. The stationary source emissions used governmental estimates for population and economic activity growth predictions to estimate exogenous changes. The models included internal changes by using 'control factors', designed to incorporate the impact of the 1990 Clean Air Act Amendments on sources. The biogenic emissions are only approximate estimations due to the large potential variability of human and other biological activity.

The base vehicle emissions for New York and Dallas-Fort Worth were predicted for 2005 and for Los Angeles in 2010, on the assumption that all light duty vehicles (LDVs) use the average industrial gasoline, and that the AQIRP test fleet was representative of the entire US LDV fleet. Each of the various technology types in the AQIRP fleet was weighted to reflect the projected composition of the future LDV fleet. However this projected fleet did not include high emitters, high mileage vehicles or poorly maintained vehicles (which produce a much higher amount of emissions per km than the well maintained test vehicles). It also ignored all off-road and medium and heavy duty vehicles and all non-gasoline fuelled vehicles (all of which contributed a significant portion of the total US vehicle emissions in 1989).

The base emission model predicted that due to already agreed measures and relative sector growth, light duty vehicles (LDVs) will only contribute between 5 and 9 per cent of peak ozone in the three cities by 2005/2010 even with the base (industrial average) gasoline.[28]

The base fuel emission profile predictions were adapted using data from the Auto/Oil inter-industry research project to calculate the changes in emissions which occur with the reformulated test fuels[29] instead of the base gasoline. This allowed analysis of each fuel without having to rerun the entire model.

The emissions from the two methanol/gasoline mix fuels (M10 and M85, 10 and 85 per cent methanol content respectively) were also modelled.

The predicted emission profiles for each fuel were then applied to the air quality models. These were designed to predict future ozone concentrations when using each reformulated fuel by considering the factors influencing emission chemistry and dispersion and ozone formation and transportation. They were developed for the purposes of the US Auto/Oil Program by simulating a historic episode of poor air quality for each of the three cities[30] then predicting the air quality for the same meteorological conditions in future years using the new emission profiles provided by the emission models. The air quality analysis was divided into two parts. Initially a simple screening analysis was done on all the Auto/Oil tested gasolines to rank the fuels in terms of estimated ozone reduction, then a detailed analysis was conducted on the fuels which showed the greatest impact on ozone formation.

The screening analysis used a simple air quality model which followed a single parcel of air through each city ignoring all other 'parcels' and all the time before and after the selected parcel's journey. The detailed analysis was used to estimate the magnitude of these reductions for the best fuels. It modelled each of the six fuels individually, simulating the air quality for the whole modelling region for the entire pollution episode.

The screening analysis of all test fuels showed that in all three cities the four fuels with the

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[28]*Auto/Oil - Air Quality Improvement Research Program: Air Quality Modelling Results for Reformulated Gasolines in Year 2005/2010,* Technical Bulletin No.3, AQIRP, Coordinating Research Council, Atlanta, 1996, p.1.

[29]The models could only model test fuels with complete data sets from AQIRP. Fuels D, E, I, J and N were not tested for evaporative emissions on any of AQIRP's current fleet and without this data, they could not be modelled. See the Research Project Test section for a further discussion of the reasons behind this omission.

[30]These historic episodes were:

Los Angeles	5–7 June 1985
New York	21–22 July 1985
Dallas-Fort Worth	29–31 August 1985

greatest reductions of ozone had low olefin content and low T_{90}. These were AMot, amot and Amot[31] and the emission certification gasoline, which had slightly higher olefin and T_{90} levels but lower sulphur levels which has an indirect impact on ozone formation via catalyst efficiency. These were selected for more detailed analysis with fuels amOt and amoT (which were included to investigate the individual effects of low olefin content and T_{90} on air quality). Fuel aMot was not among these fuels because it was not included in the air quality study – for the reason that its test data (for evaporative emissions) from the research programme were incomplete.

Overall the most effective fuel (in terms of maximum ozone reductions) in all three cities was fuel C (AMot) but after this the order varied in each city, due to contrasting emissions and meteorological differences. The level of aromatic or MTBE content did not seem to have a significant impact on ozone emissions. However it should be remembered that these increased other harmful emissions.

Gasoline reformulation could lower light duty vehicles' (LDV) contributions to peak ozone by between 15 and 26 per cent by the years 2005/2010 (depending on the city). The exact magnitude of the impact depends not only on the fuel reformulation, but also on the local air chemistry, dispersion patterns, topography and urban emission profile.

Cost Study

The third component of the US Auto/Oil Program (AQIRP Phase I) consisted of two studies into the economics of gasoline reformulation and methanol/gasoline mix fuels. They estimated the incremental cost of altering the fuel properties (costing parameters both individually and in combination) considered in the inter-industry research project relative to conventional gasoline. The cost study of the US Auto/Oil Program did not look at the cost or the most cost-effective way of meeting the reformulated gasoline targets or even of reducing air pollution in general. It just estimated the cost of producing the levels of the test parameters in commercial gasoline, regardless of their impact on ozone formation (some of them actually increased ozone formation).

The incremental costs for modifying each parameter or combination of parameters (relative to conventional gasoline) was divided into three terms; investment, manufacturing and fuel economy

[31] A/a = high/low Aromatics, M/m = high/low MTBE, O/o = high/low Olefins, T/t = high/low T_{90}. Hochhauser A.M. et al, 'The Effects of Aromatics, MTBE, Olefins and T_{90} on Mass Exhaust Emissions from current and older Vehicles,' in *Auto/Oil Air Quality Improvement Research Program* SAE-920, Warrendale, 1992, p.87.

costs. Investment costs are the capital costs required to modify equipment and facilities for the gasoline reformulation. Manufacturing costs is the total incremental refining cost, and includes extra raw materials, operating costs, capital recovery and ongoing upgrading costs. These are all heavily dependent on the existing technology and original gasoline composition and quality, which can vary substantially between areas and even refineries, so a range of costs is given. Fuel economy costs occur when there is a difference in the energy content of reformulated and conventional gasoline, requiring more fuel to travel the same distance. These costs represent this loss (or gain) in fuel economy.

The parameters (or combination of parameters) were raised or lowered to their designated level, then the other AQIRP parameters were 'floated' and a LP (linear programming) model was used to determine the combination of unspecified parameter levels that minimized cost. This had to be calculated for several gasoline scenarios as incremental costs are not directly additive. This is because altering the concentration or level of one parameter sometimes has a complementary effect on another. This can be seen in the case of aromatics and MTBE, where there is no additional cost for altering MTBE levels when reducing aromatic content. See Table 2.4 for more details.

Final Results of the US Auto/Oil Program

The results of the US Auto/Oil Air Quality Improvement Research Program were presented in two parts. The first giving the impacts of fuel reformulation on primary emissions NO_x, CO, VOCs and air toxics, and on concentrations of the secondary pollutant tropospheric ozone (from the testing and air studies). The second report gave the incremental costs of modifying each (or a combination) of the fuel parameters. These two sets of information (which are summarized in Tables 2.3 and 2.4) were given to the regulators (the EPA and CARB) to enable them to make informed decisions on the best way to control road transport emissions and to devise cost-effective air quality legislation.

Implementation

Both the EPA (US Environmental Protection Agency) and the CARB (Californian Air Resources Board) considered the results of AQIRP when determining new regulatory limits. The CARB have produced reformulated gasoline specifications partially based on the Auto/Oil information (which was then tested as the Californian Reformulated Gasoline in Phase II). The EPA has incorporated the Auto/Oil results into the complex emission model used to develop sound control regulations.

Table 2.4:

Incremental Costs for Controlling Gasoline Parameters Individually and in Combination

Gasoline Property	Control Level	Investment dollars/BPD*	Mfg Cost** cents/gal*	Fuel Economy Effect Cost cents/gal*
Sulphur	50 ppm	600-1600	2.1-4.6	0
Aromatics	20%	2300-3800	2.3-4.7	3.1-4.6
MTBE	15%	2100-3500	1.3-4.0	2.7-4.0
Olefins	5%	800-1500	2.2-3.1	0.3-0.4
T_{90}	280°F	2700-4600	5.0-8.8	2.9-4.2
Aromatics and MTBE	20%/15%	2300-3800	2.3-4.7	3.1-4.6
T_{90} and aromatics	280°F/20%	2900-4800	5.0-9.4	3.3-4.7
Olefins and aromatics	5%/20%	2900-4900	3.8-7.9	3.1-4.9
Oxygenate, olefins, T_{90} and aromatics	15%/5%/280°F/ 20%	3600-5900	7.0-11.6	3.6-5.1
Oxygenate, olefins, T_{90} and aromatics	15%/5%/310°F/ 20%	2300-3800	2.3-4.7	3.1-4.6

* 1989 dollars and base gasoline volume (BPD = barrels per day)

** Includes capital recovery, operating and raw material costs

Source: Colucci J.M. & Wise J.J., 'Auto/Oil Air Quality Improvement Research Program – What is it and What has it Learned?' in *The Vehicle and the Environment, XXIV FISITA Congress 1992*, The Institute of Mechanical Engineers, London, 1992, p.77.

The oil companies also used the data to calculate the optimal specifications for reformulated gasoline. This gave them operational flexibility, allowing them to produce the most effective fuel in each individual refinery. There are many different ways in the USA of meeting the required emission reduction targets (from the Reformulated Gasoline Plan), given all the possible combinations of the emission reducing parameters. The costs of each fuel may vary between states, areas and even refineries, due to differences in base fuels, facilities and current equipment, which means the optimal reformulated fuel specifications can be different in each case. Several of the US companies were already developing market reformulated fuels before the end of the Auto/Oil Program.

Several of the test methods used in the Program were developed specifically for it, and are now in common use in various companies, industrial bodies and governments. This includes methods to measure running loss emissions and determine speciated hydrocarbon emissions. The mathematical equations that predict emissions as a function of fuel properties devised during the Program are also in common use.

The Future

The Program considered in this paper was Phase I of AQIRP, Phase II ran from 1993 to 1997 and has now concluded. It considered the potential within future vehicle technology and points of interest raised in Phase I. These include testing at incremental sulphur concentrations to investigate linearity, considering distillation effects (coupling T_{90} with aromatics) and further work on RVP and MTBE effects. It looked into the impact of reformulated fuels on high-emitting vehicles and other 'real world' effects. More advanced vehicles were tested with the Californian reformulated gasoline (whose specifications were based on the results of AQIRP Phase I). Phase II also tested other alternative fuels, such as Compressed Natural Gas (CNG), Liquid Petroleum Gas (LPG), ethanol/gasoline mixes and pure methanol.[32] They also investigated the impact of driving cycles on the results.

Although the Auto/Oil Program has finished, the Coordinating Research Council (CRC) is still promoting cooperative research between the automotive and petroleum industries on a variety of subjects, including transport emissions and environmental impact.

[32]Colucci J.M. & Wise J.J., 'Auto/Oil Air Quality Improvement Research Program - What is it and What has it Learned?' in *The Vehicle and the Environment, XXIV FISITA Congress 1992,* The Institute of Mechanical Engineers, London, 1992, p.78.

Conclusions on the US Auto/Oil Program

The US Auto/Oil Air Quality Improvement Research Program was a large-scale innovative approach to environmental control. It demonstrated a new holistic way of working to meet environmental legislation. The Program brought together two substantial (and usually environmentally competing) industries to combine knowledge and expertise and to provide joint solutions rather than the usual indeterminate incremental controls.

The objectives of the Program were to 'develop data on potential improvements in vehicle emissions and air quality – primarily ozone – from reformulated gasoline, various other alternative fuels and developments in vehicle technology'. The results provide a substantial amount of systematic data on vehicle emissions from reformulated gasolines. Phase I only considered gasoline and methanol but Phase II looked at other alternative fuels (including CNG, LPG and an ethanol/gasoline mix). They did consider the impacts that improvements in vehicle technology might have (in Phase II), but only in terms of the fleet average, not individual technology changes.

The US Auto/Oil Program encountered many obstacles during its run (both minor and major) and has been the target of external criticisms. I have discussed many of these problems in the context of the programme, but a more general one is its ambitious scope. A very broad range of fuel parameters were tested, but due to time constraints on the project they were only able to test each parameter very briefly and at the simplest level, ignoring much of the complexity of the relationships.

Another major failing of the Auto/Oil members was the lack of forethought shown in selecting a representative test fleet, which led to the abandonment of one set of vehicles; and results during the testing as the older vehicles were recognized as being obsolete.

The necessary changes in air quality were calculated by assuming that the laboratory data (with exact specification test fuels, well maintained vehicles and laboratory test cycles and conditions) were representative of the entire real in-use fleet. The final test fuels were also unrealistic, as they contained parameters at unusually high or low levels, making most of them unlike any current or potential marketed fuel. This was aggravated by the lack of emission data at intermediate levels. It also meant that estimating the incremental costs of producing the test gasolines was of debatable value, as most of the test fuels in AQIRP were not realistic of potential industrial gasolines.

In general, the Auto/Oil Program displayed a preoccupation with urban air quality to the neglect of everything else; for example one of the test parameters, oxygenates, can have a positive impact on road transport emissions but also causes potentially serious water contamination and has an unpleasant odour. These factors were not considered.

The data produced by AQIRP have been used by various US regulatory bodies, including the EPA and the CARB to help devise new regulations. The Auto/Oil Program results are now an important integral part of the information base on the impact of fuel specifications on emissions and air quality, and have already been used within US oil companies to produce market reformulated gasoline.

Several of the test methods developed for the programme are now widely used as are the mathematical equations that relate fuel formulation with emissions (and air quality).

The US Auto/Oil Program has also influenced other industries, prompting several similar science-based self-regulatory projects, not least the European Auto/Oil Programme.

3. THE EUROPEAN AUTO/OIL PROGRAMME

The European Auto/Oil Programme was largely based on the US version, but with several important differences as a result of the contrasting air quality problems and historic approach, especially in terms of legislation. These differences are considered below, followed by a discussion of the programme, highlighting the differences in methodology, choice of parameters and general approach and the motivations behind them.

Air Quality in Europe

In general Europe has slightly better urban air quality and less immediate air quality problems compared to the United States. This is due to the lower level of urbanization (a substantial proportion of the US population lives in cities) and lower densities of industry, transport and general consumption (which is largely responsible for the heavy localized pollution in the USA). However it also has different topography, air systems and existing fuel and vehicle quality.

Perhaps the most notable difference between European and US air quality is the lack of a carbon monoxide problem. Carbon monoxide in Europe has been predicted to be within even the more stringent of the WHO health guidelines by the year 2010. This is due to the impact of mandatory implementation of catalytic converters to all new passenger cars from 1 January 1993 (which are predicted to reduce carbon monoxide and benzene by an average of approximately 60 per cent by 2010). Benzene and 1,3-butadiene are also predicted to meet health guidelines, although new measures are required to meet particulate matter, nitrogen oxides and ozone levels.

Pollution transportation is much less significant in Europe than in the USA (where it is one of the most important factors affecting air quality), due to different air current systems. Europe has a much more heterogenous topography, with several mountain ranges breaking up the region, leading to less long distance air currents which discourages long range pollution transportation. However the heterogeneity also means there are a substantial number of European cities in topographic basins, causing frequent episodes of temperature inversion and pollution accumulation. Several cities also suffer from significant short distance transportation, for example London's poor air episodes in recent years have been caused by temperature inversions forcing emissions from power stations in the east into the London air.[33]

There is a wide range of climatic variations across Europe. The warmer, sunnier cities of the Mediterranean, for example, have much worse ozone problems (and more frequent temperature inversions). In general the Mediterranean cities are poorer, with less personal wealth and therefore lower quality vehicles and fuels and less effective emission controls, vehicle maintenance and upgrading. This wealth distribution when combined with the climatic variation across Europe has led to a dramatic gradient of air quality across Europe. Athens in particular has famously bad air due to its poor fleet, sunny climate and location in a deep basin, even having unexpectedly high CO concentrations (although its climate would predict otherwise), due to poor vehicle and fuel quality.[34]

The average European gasoline differs from the average US fuel in several ways – the European has lower sulphur concentrations, higher octane levels and higher benzene and aromatic content. The lower sulphur levels reduce the efficiency of the catalyst, increasing the total exhaust emissions; the higher octane levels reduce engine efficiency and lower benzene and aromatics content. Consequently, there are less emissions of benzene and volatile organic compounds, reducing ozone formation and carcinogenic air pollution. The lower octane and sulphur levels mean that fuels in the USA are more polluting than those in Europe. However this may be partially compensated by the more advanced vehicle technology in use in the USA.

The air quality considered in the Auto/Oil Programmes is not directly comparable in Europe and the USA, as they used different definitions for quality. The United States is attempting to tackle the worst pollution problems, considering the average air quality problems in its worst affected areas, whereas Europe considered the average problems of all European cities. This means that the USA will always have worse 'air quality' than Europe.

Air Quality Legislation in Europe

Since the 1950s, when air pollution was perceived as damaging to human health, the countries of Europe instituted various national laws attempting to control local transport emissions. Past legislation has reduced pollution (particularly sulphur dioxide) from stationary sources, although in Europe, like

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[33] WHO/UNEP, *Urban Air Pollution in Megacities of the World,* World Health Organization, United Nations Environmental Programme, Blackwell, Oxford 1992, p.124.

[34] The poor fleet quality is exacerbated by the slow turnover, delaying improvements seen elsewhere as a result of new technologies (such as catalytic converters). It is predicted that over half the road transport emissions in Athens in 2010 will come from pre-1993 vehicles.

the USA, the increasing industrial base countered some of these gains.

The European Community (EC) has been implementing Europe-wide legislation since 1970. However, this only became important after the OECD study on long-range transportation showed that pollution could travel long distances and therefore across borders. Long-range control was initially used on sulphur dioxide emissions and acid rain, but is now considered an important factor in all attempts to improve air standards.

The single market drives the EC to favour measures which are harmonized across its area. However, as discussed in the air quality section above, there are substantial differences between cities in Europe, due to topography, climate and social situation. Ninety per cent of EC cities only exceed the WHO recommended levels occasionally and moderate measures would be sufficient to bring their current air quality within the guidelines. In such cases the requirement is a long-term one – to keep this level of quality despite the increasing number of vehicles on the road and congestion. The other 10 per cent (mainly southern European cities, such as Athens, Milan and Madrid) have severe pollution problems and require extensive technical and non-technical measures.[35] This will and is causing serious complications for any Europe-wide objectives or proposals.

The more immediate problems in the United States make the auto and oil industries focus on their local air quality and direct health threats such as ozone and carbon monoxide. However the European Community also considers the emissions of carbon dioxide (CO_2), the main global climate change gas. This does not affect the local urban air quality directly as the changes in engine efficiency due to reformulated fuel are insubstantial, but there are significant increases in CO_2 emissions (and other pollutants) from the reformulation process at the refinery.

Legislation on transport emissions has contributed considerably towards mitigating some of Europe's problems but has not always had the expected effect on air quality, through insufficient understanding of the relationships between fuel parameters, vehicle technology and emissions. In recent years increasing research has provided more information and the effect of each pollutant and the processes behind them – such as speciation and ozone formation and transportation – have become clearer, which can now be used to improve the effectiveness of transport emission control.

Factors behind the Programme

The European Auto/Oil Programme was triggered by a request in November 1991 (two years after

[35] 'The European Auto/Oil Programme – Questions and Answers', *AEA Policy Review,* Issue no.14, March 1996, p.15

the initiation of the US Auto/Oil Program) to the automotive and oil industries for an assessment of the best solutions to Europe's transport pollution problems.[36]

The European automobile and oil industries were at that time under strict control from several previous EC directives on transport emissions and ozone pollution[37] of which the transport sector is the main source. The European vehicle population has been growing continuously, leading to increasingly stringent emission legislation in an attempt to control air pollution. These legislations were becoming more difficult and costly to achieve. The auto and oil industries felt that some of the directives were inefficient and illogical, and they wanted to be more influential in the design and introduction of new legislation. They also wanted the legislation to include a realistic lead time, to enable the industries to plan ahead and therefore actually achieve the targets. In the past the European Parliament had generally legislated for virtually instantaneous implementation, which the industries had problems meeting. The auto industry estimated that it needed at least three years to develop and get type approval for new vehicle types. The US EPA already allowed time between legislation and mandatory implementation.

The industries also felt that they had been unfairly focused on by regulators as it is relatively easy to regulate gasoline composition or vehicle quality compared to implementing inspection and maintenance programmes or large-scale traffic management, both of which can be significantly more cost-effective (though less convenient) than fuel or engine modifications. The auto and oil industries wanted the EC to consider these and take a more holistic approach to air quality, which might reduce the pressure (and cost of meeting regulations) on themselves. A format like the US Auto/Oil Program could quantify the potential for these options and therefore make it harder for the EC to ignore them as cost-effective alternatives.

Several companies in each industry felt they were being held back from meeting environmental limits by the other industry. The auto industry blamed the variability of fuel specification and quality from preventing implementation of sensitive emission control technology, as many of the European vehicle models had already met the stricter US standards to enable sales in the US market. The oil industry blamed the 'antiquated' vehicle engine technology used in Europe and felt that, in comparison to vehicles, the impact of fuels on emission levels was insignificantly

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[36]Palmer, F. H., *European Programme on Emissions, Fuels and Engine Technologies,* ACEA/EUROPIA 1996, Ch 01/P.5.

[37]COUNCIL DIRECTIVE 92/72/EEC in *European Community Environment Legislation, Vol.2 - Air*, Office for Official Publications of the European Communities, Luxembourg 1996, p.143.

small.

Working together on a programme like the US Auto/Oil could increase the potential for finding further emission reducing options. It would also give the two industries a chance to resolve the ongoing competition as to who was responsible for the transport pollution problems and should therefore bear the brunt of the cost of improvement. This was not applicable in the US case as improvements to the vehicle technology were not considered in Phase I of AQIRP.

In addition, both industries were under indirect pressure from the environmental lobby which had gained supporters and influence. Market forces had shown that the public image of a petroleum company had become important to consumers, who had demonstrated their power in several situations. This pressure was exacerbated by the threat from alternative propulsion systems and fuels, which have just been given financial support by the European Community,[38] and are seen by regulators and the public as being significantly more environmentally friendly.

Some bodies in Europe were also irritated by the USA being viewed as the world leader in emission control, with a reputation for tough standards and regulations, and they wanted Europe to try to take the lead through more forward thinking research and solutions.

In September 1992 the European Commission organized a Symposium on 'Auto Emissions 2000' to canvas relevant interest groups, including governments, industry and environmental groups. There was a discussion on the long-term European policy on passenger car emissions through the themes of traditional and alternative propulsion systems, fuels, research activities and technical and complementary regulations.[39] It was found that general opinion favoured an integrated approach to achieving air quality rather than an attempt to regulate individual aspects of vehicle emissions, by finding and using the optimal fuel and engine technology combination. There was also a consensus that objectives should be in terms of air quality targets rather than specific emission limits.[40] This was a major change in approach for European regulation, and meant that inspection and maintenance schemes and traffic management non-technical measures could be used as an alternative to

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[38]COUNCIL DIRECTIVE 91/441/EEC in *European Community Environment Legislation, Vol.2 - Air*, Office for Official Publications of the European Communities, Luxembourg 1996, p.305.

[39]Commission of the European Communities, *European Symposium "Auto Emissions 2000", "Stage 2000" of the European Regulations on Air Polluting Emissions of Motor Vehicles, Proceedings of the Symposium,* Office for Official Publications of the European Communities, Luxembourg 1993.

[40]Commission of the European Communities, *Communication from the Commission to the European Parliament and the Council,* Office for Official Publications of the European Communities, Brussels, 1996, p.4.

technological where more practical or cost-effective.

It was felt that reductions in vehicle emissions still had potential to improve air quality, but that for this too, a more holistic view was required. It had become obvious that there were significant gaps in our understanding of the technical processes taking place and the impacts of individual measures on fuels and engines. What research had taken place was either out of date compared to the new technologies being developed or currently in use, or was not applicable to the particular situation in Europe.

In the past, European legislation had automatically followed Best Available Technology (BAT) or Best Available Technology Not Entailing Excessive Cost (BATNEEQ). This was felt to impose unnecessary pressures and costs on the industries concerned as the technology sometimes far exceeded its air quality targets. The Auto/Oil Programme approach departed from this system and attempted to achieve the required air quality targets at the least cost.

In July 1993 the European auto industry (as represented by ACEA[41]) and oil industry (EUROPIA[42]) signed a formal agreement to embark upon a three-year joint research project in collaboration with the European Commission.[43]

The Programme

The European Auto/Oil Programme was run by the European automotive and oil industries and the European Commission between 1992 and 1996; this three-way partnership meant it was also known more formally as the Tripartite Initiative on Air Quality, Emissions, Fuels and Engine Technologies. Its aim was 'to provide policy makers with an objective assessment of the most cost effective package of measures including vehicle technology, fuel quality, improved durability and non-technical measures, necessary to reduce emissions from the road transport sector to a level consistent with the attainment of the new air quality standards being developed for adoption across the European Union'. This was officially set out in the European Community Directive 94/12/EC (Article 4).[44]

The framework of the Programme was inspired by the US Auto/Oil Program and had an

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[41]ACEA is the Association des Constructeurs Européens d'Automobiles.

[42]EUROPIA is the European Petroleum Industry Association.

[43]Palmer, F. H., *European Programme on Emissions, Fuels and Engine Technologies*, ACEA/EUROPIA 1996, Ch 01/P.02.

[44]Official Journal of the European Community L100, 19.4.94, p.42.

identical three component structure; an inter-industry research project, an air modelling study and a cost study. The European programme was independent of the US Program, but was designed to fill in the gaps left by existing studies, including the US one. However, in some cases the Europeans either did not agree with the US results or felt they were not applicable to the European situation, with the result that there was some repetition.

In the United States the auto and oil industries funded and ran the entire programme, but in Europe the industries were only involved directly in (and funded) the research project. The air and cost studies were funded by the European Commission and run by academic air modellers and accountants. This may have aggravated the tension between the two industries as they were not able to negotiate a 'fair' methodology or choices and therefore did not have to take responsibility for the final results.

Although the European Auto/Oil Programme had the same structure as the US Program, there were significant differences in the variables tested due to contrasting air quality problems and legislation and the change in existing data. These disparities produced results with very different implications. They are summarized in Table 3.1.

Several of the companies included in the European Programme were multinationals directly involved in the US programme. In the oil industry, these included BP International, Conoco, Exxon International, Mobil, Phillips, Shell and Texaco, all very influential companies. The auto industry also had some overlap, with Ford and the General Motors Group (as Opel) being involved in both programmes. However in most cases the two programmes were considered independently by the sections of the companies in Europe and the USA. This is due to the structure of the multinational oil companies, General Motors and Ford (the exception to the rule). The oil multinationals essentially act as an associated group of companies working independently in each region. The top management of these multinationals were involved in both programmes but the two Auto/Oil Programmes were basically run as independent projects, with the only contribution from one to the other being a paper review of the results. The General Motors Group also treated the two programmes as unconnected, because of their structure (many companies within an umbrella company). The Ford Motor Company is the notable exception, even using the same personnel and testing laboratories in both programmes.

Ford considered the European Auto/Oil Programme critical in terms of legislation improving air quality problems caused by road transport. It is the second largest auto multinational in the world and took a leading role in the programme, undertaking 40 per cent of all the gasoline and diesel vehicle testing, despite the multitude of oil companies involved in the Programme.

Table 3.1:

Selected Differences between the US and the European Auto/Oil Programmes

	UNITED STATES	**EUROPEAN**
Period	1989-1992	1992-1996
Types of Fuels	gasoline; methanol/gasoline	gasoline; diesel
varied gasoline fuel parameters	A: aromatics, T_{90}, olefins, MTBE B: RVP, ETBE, ethanol, D: sulphur	A: aromatics, E_{100} B: sulphur
gasoline pollutants measured	NO_x, CO, Fuel Economy Volatile Organic Compounds, Over 140 different species of hydrocarbons,	NO_x, CO, Fuel Economy, Volatile Organic Compounds, Over 150 different species of hydrocarbons, Carbon Dioxide (CO_2)
Vehicles	LDV	LDV (and HDV– diesel only)
Types of gasoline fuelled vehicles	current & old (representative of current fleet composition)	advanced/prototype (representative of range of available technology in 2000)
cycle used	modified ECE-15 +EUDC	FTP-75
emissions tested	Exhaust (engine-out & tailpipe), Evaporative & Running losses	Exhaust (engine-out and tailpipe)
pollutants in Air Modelling Study	ozone	ozone, CO, NOx, benzene
Cost Study	incremental costs of changing the tested parameters, no measure of cost effectiveness or air quality improvement cost	Cost effectiveness
Measures considered in Cost Study	fuel	fuel, vehicle, non-technical measures

The European Programme failed to consult the European Parliament or the European Member States – all of which like to be involved in a process rather than simply implementing the final results. By omitting to incorporate this wider view during its run, those involved caused serious political problems. In the USA interested bodies were consulted, such as the EPA and CARB (as well as other government departments and vested interests) at every stage of their programme.

Inter-industry Research Project

The inter-industry research project was known as EPEFE (the European Programme on Emissions, Fuels and Engine Technology) and was designed systematically to advance scientific understanding of the synergetic relationships between fuel parameters, engine technology and vehicle emissions. EPEFE involved over 2000 tests on sixteen gasoline-fuelled vehicles with twelve test gasolines and 24 diesel engines with eleven test diesels during the years 1993–5.

Fuels. Among those tested in the two Auto/Oil Programmes, gasoline is common to both, but the Europeans tested diesel while the USA examined the potential of methanol/gasoline mixes. This paper is intended as a comparison of the US and European Programmes, so will only discuss non-gasoline fuels to the extent of why they were included in one programme and ignored in the other.

The European Programme did not consider alternative fuels – such as the gasoline/methanol mixes tested in the USA – as they have considerably less of the market share in Europe and are more expensive and difficult to obtain because of the lack of an adequate distribution and supply system. The United States (especially the Midwest) already has an alternative fuel supply due to substantial biofuel agriculture, so it is more practical and cost-effective and therefore viable. However, the European automobile manufacturers, like their US colleagues, have been developing alternatively fuelled vehicles, including electric, flexible and variable fuelled vehicles as well as gaseous powered vehicles (especially using CNG).

Investigating diesel effects was a priority for the European industries since there are significant numbers of diesel fuelled vehicles on European roads and because there was much less recent and applicable information available (noticeably so after its exclusion from the US Auto/Oil Program). On the contrary it is not considered important in the USA as, although 17 per cent of all transport fuel used was diesel in 1989, none of this was used in on-road vehicles.[45] It was almost entirely used in agricultural vehicles which were considered separately in the 1990 Clean Air Act Amendments.

For these reasons, diesel was felt to be more important to the European situation than alternative fuels and the severe time and money constraints on the European testing programme (all testing and analysis had to be completed in twelve months) meant only one could be tested.

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[45]International Road Federation, *World Road Statistics*, IRF, Geneva, 1992, p.102.

Gasoline Parameters. The European Programme, like the US, investigated a number of gasoline parameters, which were selected through a study of prior work (including a review of the results of the US Program, AQIRP). AQIRP's results were not always directly applicable to the European situation, partly because of the variations in basic fuel composition between Europe and the United States which affect the type and quantity of emissions produced (see European Air Quality Section for more detail).

Only three parameters were tested in the gasoline section of EPEFE – Aromatic content, E_{100} (the evaporative temperature[46]) and sulphur content. This was substantially less than in the USA where eight different gasoline parameters were tested. The Europeans did not test oxygenates, olefins, T_{90} (90 per cent distillation temperature) or RVP (Reid Vapour Pressure).

Oxygenates in the US Program were investigated as a possible way of reducing carbon monoxide (CO) emissions. European cities only exceeded the CO health guidelines very occasionally in 1992 and this has been predicted to improve dramatically to complete compliance by the year 2010. Therefore oxygenates including MTBE & ETBE (Methyl- & Ethyl-tertiary-butyl-ether) and ethanol were not included in the European Programme. Historically they have only been used to boost octane levels and as a possible aromatics replacement in the EC and, as the US industries have discovered since their Auto/Oil Program, they can have significant disadvantages including serious water contamination, an unpleasant odour (which is important to the customer and therefore the companies' competitiveness) and an increase in nitrogen oxides emissions (which are the key driver emissions in the European Programme).[47]

The distillation temperature, T_{90} (the temperature at which 90 per cent of the fuel has evaporated), was not included in the European Programme; however they did look at the effect of the evaporative temperature, E_{100}, which is inversely related to T_{90} . E_{100} and T_{90} are both measures of volatility (although E_{100} represents mid-range volatility and T_{90} back-end volatility). It was simply regional convention that the USA and Europe used different measures. The US measurements showed that, when not controlled, E_{50} (the equivalent of T_{90}) was highly correlated to E_{100} . The Europeans have historically tested E_{170}, E_{100} and E_{150}, but they felt that mid-range volatility (E_{100}) was more important to their situation than back-end.

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[46] E_{100}, the evaporative temperature is the percentage of fuel that has evaporated at 100°C.

[47] *Alternative Fuels for Road Transport*, CONCAWE, vol. 5, no. 1, April 1996.

The Reid Vapour Pressure (RVP)[48] was excluded as it mainly influences evaporative and running loss emissions (shown in the US Program) which were not tested in the European Programme, for there was already sufficient information available from the USA. The US results for evaporative emissions were deemed only 'moderately reliable' but evaporative emissions tests are highly sensitive and therefore the results were considered acceptable under the European time constraints. RVP is also linked to the evaporative temperature E_{100}, which was tested in detail.

There was also felt to be adequate information on the impact of olefin content on vehicle emissions, so these were excluded from the testing programme but included in the final proposal to the European Parliament.

The parameters were tested in two matrices, the first varied E_{100} and aromatics, to determine individual and interdependent effects, and the second had varying levels of sulphur. Unlike the US Program which tested each parameter at either 'high' or 'low' levels, the Europeans tested each parameter at several levels. This gave more information about the impact of certain changes on emissions, investigating the linearity of the relationships.

The European Auto/Oil Programme blended twelve gasolines with different levels of these parameters and essentially constant levels of all other physical and chemical parameters.
These were blended into two groups of fuels, with one fuel common to both. The levels of the parameters under investigation are shown in Table 3.2.

Gasoline has a rigid set of physical and chemical properties necessary for engine performance and fuel economy, and these impose further limitations on the composition of reformulated gasolines. It is extremely difficult to vary one parameter in isolation as parameters have interdependent effects on the performance required properties and on each other. Both programmes doped the fuels to achieve the necessary test levels. The US Program was criticized for keeping the other parameters constant by doping the fuels with compounds that would never be found in gasoline under normal circumstances and that may have unknown effects.[49] This was a valid criticism at the time of both AQIRP Phase I and the European Auto/Oil Programme, however US Phase II tests showed that most compounds used did not have a significant effect on the results.

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[48]The Reid Vapour Pressure (RVP) is a measure of fuel volatility.

[49]McArragher, J. S., 'The US Auto/Oil Programme and its Relevance to Europe' in Commission of the European Communities, *European Symposium "Auto Emissions 2000", "Stage 2000" of the European Regulations on Air Polluting Emissions of Motor Vehicles, Proceedings of the Symposium,* Office for Official Publications of the European Communities, Luxembourg 1993, p.208.

Table 3.2:

The Test Fuel Matrices from the European Auto/Oil Programme

Matrix EPGA, varying aromatics and E_{100} independently (sulphur is approximately 100mg/kg)

Fuel	**Aromatics % v/v**	**E_{100} % v/v**
EPGA1	24.1	40.7
EPGA2	37.0	36.3
EPGA3	51.1	36.5
EPGA4	19.5	51.4
EPGA5	35.2	51.0
EPGA6	48.3	50.3
EPGA7	20.3	64.5
EPGA8	34.1	61.8
EPGA9	43.8	59.9

Matrix EPGS, varying Sulphur
while keeping E_{100} and aromatics constant (approximately 19.5% and 51.4% respectively)

Fuel	**Sulphur mg/kg**
EPGS1	18
EPGS2	95
EPGS3	182
EPGS4	382

EPGA4 = EPGS2

Source: *European Programme on Emissions, Fuels and Engine Technologies,* ACEA/EUROPIA 1996, Ch 02/P.02 & Ch 03/P.02

Several of the European fuels eventually tested were unlike any real market gasoline, as they contained abnormally high or low levels of certain parameters. This meant they were more likely to pick up incorrect results caused by any interdependent effects these abnormal parameters may have had on those under investigation. This fault was also seen in the US Program.

Gasoline Pollutants. The European Auto/Oil Programme measured the same pollutants as the US Program (NOx, CO, HC and VOC) with the notable addition of carbon dioxide (CO_2), the main global climate change gas.

Carbon monoxide emissions were measured despite the predictions of automatic 2010 compliance with health guidelines, to investigate any changes (positive or otherwise) on emission levels brought on by proposed fuel and vehicle modifications.

In Europe urban nitrogen oxides are considered the key driver emission. This means when NO_x is reduced the other pollutants will follow (generally, however there is a trade-off with specific hydrocarbons). This is in direct contrast to the USA, where the focus was on the VOC emissions (the other ozone precursor).

The pollutants examined both in the European and US Programmes were the historically important ones. For example, both programmes excluded particulate matter (PM_{10} and $PM_{2.5}$)[50] emissions from gasoline, despite increasing concern about its effects on human health and the role of gasoline transport in its formation. Particulate matter from diesel was investigated in the diesel research section of EPEFE, as diesel engines have long been an acknowledged source. Particulate matter was also excluded because the historic data set required for modelling is incomplete due to conflicting definitions previously in use in the European nations (including PM_{10}, black smoke and total suspended particulates).

Vehicles. The gasoline vehicles tested in EPEFE (the European Programme on Emissions, Fuels and Engine Technologies) were all advanced or prototype vehicles. They were meant to represent the range of emission control technologies that should be available in the year 2000. This is in direct opposition to the US Auto/Oil Program (AQIRP) which attempted to look at a representative sample of the current gasoline vehicle fleet (although their fleet was modified during the programme to

[50] PM_{10} is defined as particulate matter less than 10 microns in diameter and $PM_{2.5}$ is particulate matter less than 2.5 microns in diameter.

entirely 1989 models). This distinction also stems from the differences in air quality between the two regions.

In the USA more immediate options for air quality improvement were required and this involves optimizing the fuel within the current fleet. The legislation behind the US Program (the Clean Air Act Amendments of 1990 and the Reformulated Gasoline Plan) stipulated very tight specifications for the programme, which was designed to improve reformulated gasoline, not vehicle technology and traffic measures.

However, European air quality problems are not as imminent so it is possible to consider longer-term solutions to counteract the increasing vehicle population. It is also possible to consider long-term effects and modifications (such as gradual changes in fuel formulation) allowing manufacturers and suppliers time to adapt and make more severe changes economically.

The European Programme had several other reasons for not testing the current fleet, for example overlap with AQIRP, the changing vehicle population and competition.

In general, the European fleet is less advanced than that of the United States (the average 1989 US model is equivalent to the average 1992 European model), therefore using current (to the beginning of the programme in 1992) European models would probably have caused too much overlap with the US Auto/Oil Program. This time lag is mainly due to the lack of catalytic converters in Europe, with less than 15 per cent of gasoline vehicles having them in 1990 (compared to over 90 per cent of vehicles with catalysts in the USA).[51]

However, the number of vehicles with catalysts in Europe is increasing rapidly due to the EC directives requiring them in all new cars.[52] There is therefore little point in testing current vehicles, as the European fleet is changing so fast that the results would soon be out of date. The focus on future rather than current vehicles is probably also linked to the suggestion that Europe wants to compete with the USA, the current world leader in vehicle emission control.

The vehicles used in EPEFE were advanced models or prototypes supplied by the auto manufacturers involved in the programme; they contained a variety of advanced emission controls

[51] McArragher, J. S. 'The US Auto/Oil Programme and its Relevance to Europe' in Commission of the European Communities, *European Symposium "Auto Emissions 2000", "Stage 2000" of the European Regulations on Air Polluting Emissions of Motor Vehicles, Proceedings of the Symposium,* Office for Official Publications of the European Communities, Luxembourg 1993, p.212.

[52] Catalytic converters have been required in 40 per cent of all new cars since 1990 and all new cars since 1993.

and represented the range of emissions technology that should be available by the year 2000. This technology included quick start catalysts (electrically heated and close coupled catalysts) which can reach light-off (working temperature) within 45 seconds, on-board diagnostic systems (OBD), exhaust gas recirculation (EGR) and fuel injection systems. The different emission technologies were not investigated systematically like the fuel parameters, but loosely, to observe general relationships between vehicle technology and emissions.

The USA was criticized for the extreme variability between its different stocks of vehicles. The Europeans did not have two distinct sets of gasoline vehicles but nevertheless had a large range of emissions due to the extensive range of technology in the models. Some of them even produced more emissions than current models, despite being prototypes containing the manufacturers' best emission control technology. So the problem of unexplained variability, first detected in the US Auto/Oil Programme was not satisfactorily addressed in the European.

Tests. There was essentially only one test in the gasoline section of EPEFE. Every combination of the fuels and vehicle was run on a chassis-dynamometer through a driving cycle to determine exhaust (tailpipe and engine-out) emissions. This is similar to the exhaust tests from the US Program, although the USA also measured evaporative and running loss emissions.

The vehicles are preconditioned and run on a chassis-dynamometer through the current accepted European driving cycle (ECE-15 + EUDC). Each combination was tested four times, in two pairs of back-to-back tests, while the US Program tested just one pair. The inclusion of a gap between the tests gave the European programme more robust results as vehicles, fuels and emissions are very sensitive to instantaneous conditions. It also improves the statistical significance of the results, which is consistent with the approach of the European Programme, concentrating on fewer parameters with more detail to produce more accurate results.

The driving cycle is the most important discrepancy between the two sets of exhaust emissions tests, the choice of driving cycles can have a huge impact on the test results. This is due to different speeds, acceleration and cycle lengths – all of which affect engine and catalyst efficiency and therefore emissions. The test cycles also show a bias to certain vehicles as their emission control technology reacts differently to the conditions.[53] See Diagram 2, for more detail on the European test

[53]Peake, S. , *Vehicle and Fuel Challenges beyond 2000: Market Impacts of the EU's Auto/Oil Programme*, FT Automotive Publishing, London, 1997, p.33.

procedure and the ECE & EUDC test cycle.

The Europeans improved their test cycle after the USA came under fire for using the FTP-75 cycle, which was thought to underestimate emissions by 15 per cent. The standard European test cycle at that time (the unmodified ECE) had a 40 second warm-up before emissions were measured, and this was giving severe underestimations as it ignored all emissions before the catalyst was at an operating temperature.[54] It also failed to represent real driving as the average speed was under 12 miles per hour. It was modified to include a cold start (which meant emissions were collected from the moment the engine was turned on), an 11 second idle and a supplement cycle. This supplement, the Extra Urban Driving Cycle (EUDC) increased the average and maximum speeds and was felt to be more representative of 'real' European driving. This has improved the accuracy of the results collected using this cycle but it nevertheless ignores driving at higher speeds and higher accelerations, especially 'enrichment events' of extreme acceleration. These enrichment events have been known to produce up to half the amount of emissions of a cold start.[55]

The dynamometers used in both programmes have also come under fire for not accurately assessing the vehicle emissions, since they did not reproduce a real road situation – not only because of wrong speeds and accelerations, but also by neglecting some aspects of the vehicle dynamics such as drag and the impact of air conditioning (which changes the load distribution in the vehicle). This problem is under consideration in the European Auto/Oil Stage 2.

The two industries collaborated in the negotiation and the analysis but had exclusive duties within the testing process. The oil industry blended all the test fuels to the agreed specification (or as close as possible) then handed them over to the auto industry who ran the emission tests. As the vehicles tested in the European Auto/Oil Programme were all prototypes, the auto manufacturers were (understandably) concerned about disclosing their future models, so all testing was done behind closed doors at the manufacturers' laboratories. This defensive attitude may have contributed to the lack of solidarity in the auto industry which allowed the more coordinated oil industry to shift the balance of power in the European Programme.

The US used 'current' vehicles which were available to anyone, thus the testing was more open and the auto industry was more united (although this was also affected by the relative numbers

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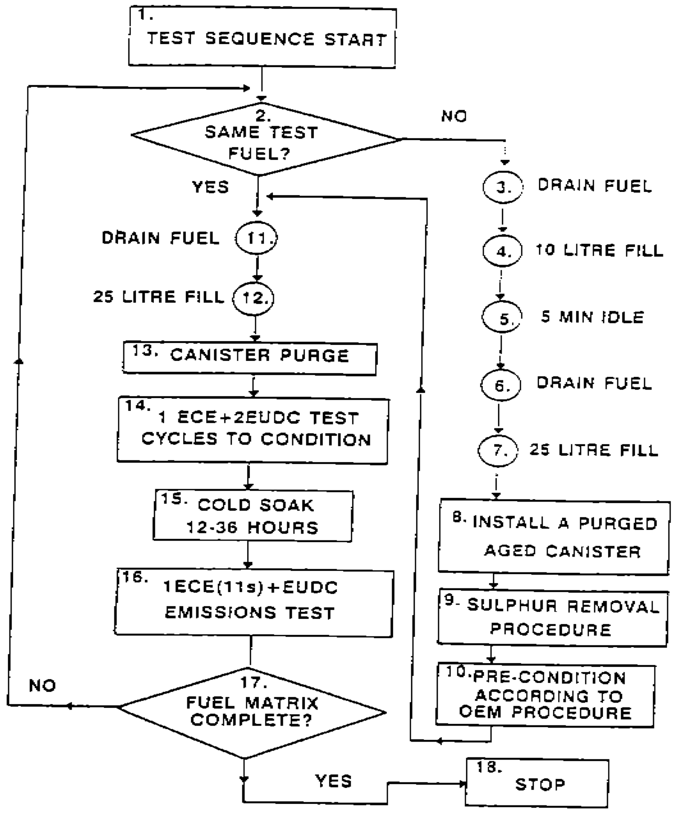
[54]Catalysts are extremely sensitive to heat, and have very little effect until warmed up to a reasonable operating temperature. When working they can reduce certain emissions by up to 95 per cent.

[55]Calvert, J.G. et al, 'Achieving Acceptable Air Quality: Some Reflections on Controlling Vehicle Emissions', *Science*, vol.261, no.5117, 2/7/93, p.40.

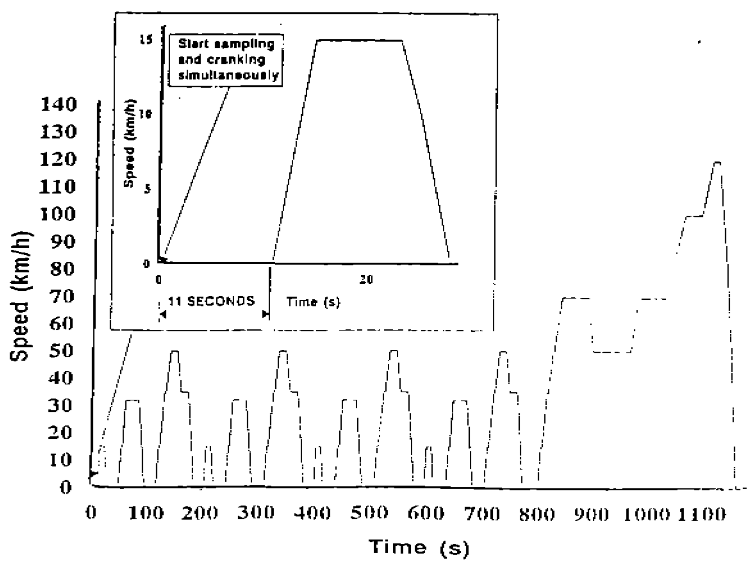
Diagram 2 **The European Gasoline Vehicle Test Procedure and Modified ECE-15 + EUDC Composite Driving Cycle**

EPEFE GASOLINE VEHICLE EMISSIONS TEST PROTOCOL



Note: Step 9 only to be run during sulphur test matrix.

MODIFIED ECE-15 + EUDC TEST CYCLE



Source: Palmer, F. H., *European Programme on Emissions, Fuels and Engine Technologies*, ACEA/EUROPIA 1996, An 01/ P.25 & P.28

involved in each programme; three in the US compared to hundreds in Europe).

EPEFE Results. The European Programme on Emissions, Fuels and Engine Technologies found several overall results, which are summarized in Table 3.3. The magnitude of the reductions is not estimated here, as the range of impacts varies extensively according to the vehicle tested. In general the effects of aromatic content and E_{100} on emission levels were greater than those of sulphur, although sulphur was the tested parameter which reduced all the measured pollutants.

Table 3.3:

Individual Parameter Effects on the Main Primary Pollutants

	Carbon Monoxide	**Nitrogen Oxides**	**Hydro-carbons**	**Benzene**	**Carbon Dioxide**	**Fuel consumption**
↓ **Sulphur**	↓	↓	↓	↓	-	-
↓ **Aromatics**	↓	↑ a	↓	↓	↓	-
↑ $\mathbf{E_{100}}$	b	↑	↓	↓	-	-

All results are for the Composite cycle (ECE-15 + EUDC)

a = Nitrogen oxides emissions decreased with decreasing aromatics while the engine was cold, but increased when warm, due to catalyst operation.

b = non-linear response, CO emissions were lowest at 50% v/v E_{100}

Fleet Average Emissions for all Sulphur Matrix Fuels over the Composite Cycle

		EPGS1	**EPGS2**	**EPGS3**	**EPGS4**
HC	g/km	0.159	0.159	0.164	0.173
CO	g/km	1.123	1.172	1.214	1.240
$\mathbf{NO_x}$	g/km	0.166	0.174	0.172	0.187
$\mathbf{C0_2}$	g/km	215.6	214.7	215.7	214.5
FC	1/100km	9.33	9.30	9.34	9.30

Fleet Average Emissions on E_{100} / Aromatics Matrix Fuels over the Composite Cycle

		EPG A1	**EPG A2**	**EPG A3**	**EPG A4**	**EPG A5**	**EPG A6**	**EPG A7**	**EPG A8**	**EPG A9**
HC	g/km	0.159	0.217	0.252	0.149	0.157	0.165	0.146	0.151	0.157
CO	g/km	1.305	1.508	1.638	1.211	1.407	1.471	1.342	1.365	1.485
NO_x	g/km	0.171	0.159	0.152	0.181	0.179	0.164	0.184	0.180	0.176
$C0_2$	g/km	217.6	222.1	227.9	214.9	221.1	226.2	215.3	219.9	224.1
FC	1/100 km	9.28	9.25	9.26	9.31	9.28	9.29	9.41	9.29	9.30

Source: Palmer, F. H., *European Programme on Emissions, Fuels and Engine Technologies,* ACEA/EUROPIA 1996

In general the first part of the test cycle produced proportionally more emissions than the rest of the cycle, regardless of the parameter under investigation (although the extent of this impact varies between pollutants). This was because the cycle was run from a cold start, and before the catalyst reached operating temperature the emissions were largely uncontrolled. The cold start also affected drivability with certain fuels – this was seen with low E_{100} fuels, where the poor drivability caused large amounts of hydrocarbon emissions in the ECE cycle.

The EPEFE results showed that the relationship between sulphur and emission levels was mostly linear, but this was not true for E_{100} and aromatics. This is an interesting result as the US Program did not test for linearity in Phase I (considered in this paper), but investigated it for sulphur in Phase II. However they did not test for the linearity of T_{90} (related to E_{100}) or aromatics.

The decrease in carbon dioxide emissions with increasing aromatic content was due to a drop in the hydrogen/carbon ratio of the fuel caused by the increase of unsaturated organic compounds. CO_2 emissions from vehicles are usually virtually unaffected by changes in fuel reformulation, but are greatly increased from the reformulation processes in the refineries (an aspect of fuel emissions not considered in either Auto/Oil Programme).

The impact of vehicle technology on emissions was significantly larger than the effect of fuel formulation on emissions, and although individual vehicles displayed a wide range of emission levels, the impact of vehicle technology showed several general trends on emissions. Vehicles with close-coupled or early light-off catalysts gave much lower emissions over the entire cycle than other catalyst vehicles. The trimetallic catalyst vehicles produced very low levels of emissions once warmed, but substantially higher levels over the ECE and composite cycles. Several engine measures, such as EGR and secondary air injection, could not be assessed directly, due to the unsystematic testing (the observed results could have been caused by more than one factor).

Air Quality Modelling Study

The second section of the European Auto/Oil Programme was an air quality modelling study which was designed to predict future air quality in Europe and, by comparing this with the target levels, determine the emission reductions required for compliance. This is in contrast to the US Auto/Oil Program which approached the problem from the other end, modelling the test fuels to see what was achievable in terms of air quality improvement. This was due to the time constraints on the European Programme, as modelling fuels on future cities takes considerably longer than modelling the future just once to find the base pollutant concentrations.

The European modelling study predicts impacts on nitrogen oxides (NO_x), carbon monoxide (CO) and benzene, as well as ozone, for the period 1990–2010; whereas the US Program considered just future ozone concentrations.

Air quality was modelled in seven 'representative' cities across Europe, with a variety of meteorological, climatic and emission conditions for a range of years between 1990 and 2010. These cities were Athens, Cologne, The Hague, London, Lyons, Madrid and Milan. They were chosen as representative of European Community (as it was in 1992) cities with adequate available emission and air quality data. There was a slight bias towards northern, richer cities where current and historical data were obtainable. These, in general, had better air quality than the Mediterranean and southern cities (see European Air Quality section for more detail) so the European study underestimated the extent, although not the severity, of the problem.

The US study only used three cities for modelling, as it was investigating air quality across the range of polluted cities. All the selected cities had severe problems, whereas the European cities were representative of all air quality types, including clean air. More cities may have been included in the European study because of the more heterogenous nature of Europe's situation and topography, but possibly also for political reasons as the nations of Europe are much more independent than the States in America.

The European air study was divided into four distinct parts. Stage 1 reviewed the current air quality in the seven cities, compiling data for the period 1980 to 1990. Stage 2 developed a predictive model relating emissions and air quality using historic data, which was calibrated by comparing the predicted air quality (in terms of NO_X, CO and benzene) with the actual results for the summer of 1990. Stage 3 predicted the emission profile for the years 2000 and 2010, considering the impact of incoming legislation and the growth of emissions from stationary and mobile sources. Stage 4 used These new emission profiles and meteorological models (for non-reactive and photochemical pollutants) of the cities and surrounding areas to predict air quality in 2000 and 2010 The highest predicted NO_X, CO, benzene and ozone levels in each city were compared to the health guidelines to define the necessary emission reductions.

The emission inventory for the years 2000 and 2010, was predicted by modifying the 1990 emissions, considering the impact on each source of already agreed legislation (both local and European) and growth. Future stationary source emissions were estimated for each city using current data and predictions of growth in energy demand and the impact of legislation, such as the EC's Large Combustion Plants Directive. Biogenic emissions were also included in the profiles, although these were all assumed to be Isoprene, a significant proportion of biogenic emissions. However Isoprene is a reactive organic compound with a noticeable effect on ozone formation, whereas a substantial amount of biogenic emissions are non-reactive Carbyl groups. This means the reactiveness and impact of biogenic emissions may have been overestimated in this model. The air quality study included a sensitivity test, to test the effect of this assumption on the air quality model.

Mobile sources were harder to predict and model at such resolution due to the small amount of emissions from many sources. This was considered in detail for each city individually, taking into account predicted growth in the vehicle population and local congestion problems (which can cause up to 35 per cent increases in HC and CO emissions and 25 per cent increases in NO_x emissions compared to a steady traffic flow situation[56]). They also considered the impact of Europe-wide changes in the emissions, such as the impact of the compulsory implementation of catalytic converters in all new cars from 1993 (which will substantially reduce CO and benzene emissions) and the introduction of carbon canisters to reduce evaporative emissions. The European air quality study considered both diesel and passenger cars, 2-wheeled vehicles, buses, and light and medium duty

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[56] Krawack, S., 'Traffic Management and Emissions,' *The Science of the Total Environment*, 134 (1993), p.305.

commercial vehicles. The US study assumed all these categories behaved like LDV vehicles, which is clearly unrepresentative; in this the Europeans were more accurate.

Two types of air quality models were used, one considering the dispersion of non-reactive pollutants (CO, NO_X and benzene) and the second considering photochemical pollutants (in this case, ozone). The models were developed for the Auto/Oil air quality modelling study, as there was no existing standard European model. They were produced using current (1990) and historical emission and air quality data and meteorological and dispersion information and were specific for each of the seven cities.

Three non-reactive air quality models modelled two periods for nitrogen oxides pollution; one period representative of annual mean meteorological conditions and one in a high pollution episode. The high pollution episode was typical rather than extreme, which means that even if the specified reductions were accomplished, the health guidelines would still be exceeded from time to time. The model assumed all non-reactive pollutants act alike in terms of dispersion and simply calculated nitrogen dioxide, carbon monoxide and benzene emissions using nitrogen oxides concentration ratios for all the different source categories.

The model also assumed that the relationship between non-reactive pollutants and air quality is linear for each source under the same meteorological conditions. This meant they only had to run the model once for 1990 and then change the emission profile to calculate the future air quality. Nevertheless, a significant amount of uncertainty is thus introduced into the model, as non-reactive pollutants do not have a linear relationship with air quality in the modelled high pollution episodes. This is because severe pollution is often aggravated by temperature inversions, which causes pollution accumulation, and this complicates the standard linear relationship.

The photochemical model used the meteorological conditions for the entire period of April to September 1990 to simulate conditions for the years 2000 and 2010. This model was more complex as the connection between photochemical pollutant concentration and emissions can not be approximated to a linear relationship.

The future air quality predictions were used to define the necessary emission reductions to achieve the air quality targets derived from the World Health Organization Guidelines. The highest concentration of CO, NO_X and benzene in each city was compared to the air quality targets and a list of target reductions was compiled. While the European Auto/Oil Programme recognized that particulate matter was important, there was not sufficient data or capabilities to model it. They specified a possible reduction in particulate matter from diesel, and resolved to study it in more depth in later Auto/Oil stages.

The report concluded that total emission levels are indeed falling, and target levels for benzene and carbon monoxide for all seven cities are likely to be attained in 2010 with already agreed measures. Nitrogen oxides, however, will need further measures and ozone levels can not be attained through transport initiatives alone.

Cost-Effectiveness Study

The final part of the Auto/Oil Programme was a cost-effectiveness study[57] which assessed the options from the other two parts in order to find the most economic package required to meet the air quality targets.[58] These options, which included fuel quality, technical improvements, inspection and maintenance programmes and non-technical measures (such as traffic management schemes) were examined so as to establish the least-cost method of reaching the World Health Organization recommended guidelines for air quality. On the contrary the US programme merely evaluated the incremental cost of implementing the parameter manipulations from the inter-industry research project and left it to the regulators to devise a cost-effective package.

The US Auto/Oil Program considered studying the cost-effectiveness of the options rather than the direct incremental costs of altering parameters to their test levels (which are largely academic in real world refineries). However, this approach had to be abandoned when it became clear that the auto and oil industries could not agree on a system for estimating the cost-effectiveness.

There are disadvantages to considering cost-effectiveness, such as uncertainties in the estimates, and the difference of costs and effectiveness across nations and regions – as a result of the differing air quality situations of specific areas and the refinery and manufacturing inputs for example. Consequently the most cost-effective formulation in one area is not necessarily optimal for the whole of Europe. Even given absolute specifications for reformulated gasoline or vehicle technology, the costs of achieving these vary considerably between areas and individual manufacturers and refiners.

The cost study group were given the targets for air quality improvements from the air quality modelling study, and converted these into reductions in emissions. They then researched costs that achieved these targets or a portion of them and the impacts of each measure, and used a cost-

[57]Palmer, F. H., *European Programme on Emissions, Fuels and Engine Technologies,* ACEA/EUROPIA 1996, Sum/ P.2.

[58]*Air Quality Report of the Auto Oil Programme,* European Commission, 1993.

effectiveness computer programme to minimize costs in achieving these emission reductions targets.

The FOREMOVE model was developed for the European Auto/Oil Programme to quantify the relationship between air quality and emissions, and was used to translate the results of the air quality modelling study into specific emission reductions.

The cost study group defined four scenarios that reduced emissions by increasing amounts, as seen in Table 3.4.

Table 3.4: Fuel Emission Reduction Scenarios

Scenario		1	2	3	4
Gasoline	CO	20%	30%	45%	70%
	HC	20%	40%	65%	70%
	NO_x	20%	40%	65%	70%
IDI Diesel	CO	25%	40%	50%	50%
	HC	10%	20%	30%	30%
	NO_x	20%	35%	50%	70%
DI Diesel	CO	25%	40%	50%	50%
	HC	10%	20%	30%	30%
	NO_x	20%	35%	50%	70%
	PM	20%	35%	50%	70%

Source: *A Cost-effectiveness Study of the various Measures that are likely to reduce Pollutant Emissions from Road Vehicles for the year 2010,* Commission of the European Communities, 1995.

The cost study looked at five types of costs – investment, direct operating costs (variable and fixed), administrative and regulatory costs associated with monitoring and enforcement, indirect costs (such as those due to a change in fuel consumption) and welfare costs (arising as a result of changes in relative costs). They investigated each of the four categories of options in turn, considered cost and impacts of meeting each of these four scenarios.

The various options were costed using several different methods. Oil costs were adapted (by adding inflation) from existing studies, primarily for the German Unweltbundesamt[59] from 1993,

[59] 'Modifying European Gasoline Composition to meet enhanced Environmental Standards and its Impact on EC Refineries' ADL/Unweltbundesamt, 1993, as quoted in European Auto/Oil Cost Study.

although this seems a little simplistic as the oil industry itself claims to be undergoing a long-awaited shakeout.[60] Auto costs were estimated from ACEA interviews and questionnaires.[61] There were significant variations in the cost estimates, depending on various factors, including existing equipment, size of the company and the local economic and fiscal situation. Inspection and maintenance programmes and non-technical measures were costed using existing literature, questionnaires and computer simulations.

These estimates of cost and impact were combined using a computer optimization model, designed to determine cost-effectiveness and therefore minimize costs in achieving these emission reduction targets. It determined the least-cost combination of mechanisms which achieved the required reduction in each of the seven cities, starting with NO_x, the key driver emission in Europe. However, this is not an emission model, so it makes several simplifying assumptions which decrease the model's accuracy, including ignoring some of the sources and some of the mechanisms which affect the sources.

Some of the non-technical measures proved to be very cost-effective, but this information is of no direct use to EU legislators (which was the European Auto/Oil Programme's objectives), as they can not be implemented at the European level. Examples of non-technical measures costed include traffic management, road pricing, cheaper public transport, and fiscal measures on vehicles and fuel, and these have to be implemented nationally or locally.

The cost estimates included a slight safety margin, to allow for variations in durability and inconsistencies during production. This may also have been exaggerated by the knowledge that the proposals would have to go through the European Parliament, an institution that has a reputation for always going one step further than the suggestion, and largely ignoring cost factors.

There are many different ways of calculating cost-effectiveness, and this was the stumbling-block in the US Auto/Oil Program that caused the intended cost-effectiveness study in AQIRP to be replaced by a study of incremental costs. It has certainly proved to be the most controversial portion of the European Programme in terms of results and impacts on the bodies involved. The oil industry has been accused of assembling fuel packages of relatively ineffectual and expensive combinations,

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[60] Knott, D., `Shakeout gathers momentum in Europe's refining sector,' *Oil and Gas Journal*, vol.94, no.13, 25 March 1996, p.21.

[61]No auto manufacturer gave data for Scenario 4, as they said it was not technically possible in terms of current vehicle technology.

which leads to an underestimation of the cost-effectiveness and viability of fuel modifications. ACEA complained that the model was biased against them, because, by only calculating cost-effectiveness for one medium-term future year, it underestimated the immediate benefits of fuel reformulations.

Final Results of the European Auto/Oil Programme

The final costs for the implementation of the Auto/Oil results are 82.5 billion ECU. This has been divided in a cost-effective manner between the automotive and the oil industry, with the auto industry paying 86 per cent of this compared to the 14 per cent to be borne by the oil industry.

Table 3.5:

Predictions of Average Percentage Changes in Road Transport Emissions by 2010, with and without Auto/Oil Result Implementation

	1995	2010, no A/O	2010 + A/O
Urban NO_x	100	62	39
Urban PM	110	56	34
Urban CO	80	47	24
Urban Benzene	87	49	25
Total VOC	90	44	24

1990 is defined as the base year (100%)

Source: 'Auto/Oil – the Commission's proposal on transport fuels,' *CONCAWE Review*, vol. 5, no. 2, October 1993.

The oil industry claim this is scientifically calculated and fair, as their costs are mostly immediate investment whereas the auto costs are mainly small increases per car caused by the addition of anti-pollution gadgets, and will therefore have a much smaller relative impact on the industry. The auto industry has responded by pointing out they do not simply put gadgets on engines and tailpipe, but need a more holistic approach to vehicle manufacture. Both industries will be affected by the cost burden on them, and this will undoubtedly cause some shift in the industry structure, but as always in the case of change, there will be winners and losers in both industries.

Implementation of Results

The initial proposals as adopted by the European Commission on 18 June 1996[62] following the Auto/Oil Programme were as follows:

Proposal for a European Parliament and Council Directive 96/0164[63] relating to measures to be taken against air pollution by emissions from motor vehicles, and amending Council Directives 70/156/EEC and 70/220/EEC

A Selective Summary

- Reduction of 20–50 per cent of the main pollutants from 1/1/2000 for new types of vehicles and 1/1/2001 for all new vehicles.

Gasoline Vehicles	*Emission Reductions*
Nitrogen Oxides	40%
Total hydrocarbons	40%
Carbon Monoxide	30%

These were felt to be key measures for gasoline, which would achieve the medium-term air quality objectives. Similar measures were also proposed for diesel emission reductions (for both direct and indirect injection vehicles).

Other measures include establishing indicative limit values for 2005, compulsory on-board diagnostic (OBD) systems on gasoline vehicles, a new test procedure for evaporative emission and production monitoring.

Proposal for a European Parliament and Council Directive 96/0163[64]
relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC

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[62] *Official Journal of the European Communities,* No. C77, 11.3.97, p.1, p.8.

[63] Commission of the European Communities 96/0164 (COD), COM (96) 248 final, Brussels, 18.06.96, p. 99.

[64] Commission of the European Communities 96/0163 (COD), COM (96) 248 final, Brussels, 18.06.96, p. 66.

A Selective Summary

- Gasoline must meet the following parameters to be sold in the member countries:

		Min	Max.
RVP	kPa		60.0
E_{100}	% v/v	46.0	
E_{150}	% v/v	75.0	
Olefins	% v/v		18.0
Aromatics	% v/v		45.0
Benzene	% v/v		2.0
Oxygen content	% m/m		2.3
Sulphur	ppm		200
Lead	g/l		0.005

- Diesel must also meet a certain specification to be sold in the member countries.
- Test methods must be run to certain specifications.

European Commission will propose a revision for this directive within twelve months of adoption, to include further cost-effective improvements to the fuel specifications (note: these are the Auto/Oil II results).

In addition member states must allow the marketing of fuels which comply with these specifications, although they can require higher quality fuels in areas of severe atmospheric pollution. They also allow for amendments brought about by technical progress.

The Auto/Oil proposals included meet times, that is to say, advance warning of the implementation of mandatory targets; these give the industries a chance to achieve the targets without entailing excessive costs. This is a departure for European environmental legislation, but was welcomed enthusiastically by the industries concerned.

The results of the European Auto/Oil Programme had to be proposed and accepted by the European Parliament, including all member nations, before they could be implemented. This has taken longer than expected, and the entire process is now surrounded by controversy, with accusations flying from both sides.

On the one hand there are the automotive and oil industries with the European Commission arguing that they did exactly what was asked of them and are now having their sound scientific results ignored for more political considerations. On the other hand, the European Parliament, and national governments have accused them of excluding the governments, environmental groups and other vested interests from the programme and producing very biased results. They also complained that the member states were not given enough time to consider the original proposals, nor were they sufficiently involved in the process (especially as they are responsible for implementing the final measures). However there are also disputes within, as the automotive industry is complaining that the cost study is unfairly biased against them, and has left them with 86 per cent of the overall implementation costs.

The members of the European Parliament have a wide variety of opinions on the proposals, especially the stringency of the emission reductions. When the two draft directives were first proposed, MEPs unanimously voted that they were not tough enough.[65] The European Parliament adopted several amendments to the draft directives in April 1997; for gasoline vehicles these included improved durability of anti-pollution equipment, a cold start test (at -7°C), and the possibility of converting the indicative emission reductions for 2005 into mandatory targets. These targets were included to give regulators something to aim for, but were designed to be scientifically quantified with the results from Auto/Oil Stage 2.

Both industries knew that the scientific results from the Auto/Oil Programme would be modified for political reasons, during the Parliament's debate, but said they were disappointed with the divergence with their results. As the debate stands, the modifications are not as extreme as some of those considered by the Parliament, but the length of debate and the number of compromises in the most recent proposals are indicative of the controversy surrounding the results. The two industries and the European Commission were against these proposed changes, especially the mandatory 2005 values, which would abandon the scientific basis of the new approach to emission regulation.

At present the Environment Council (on 20 June 1997) has reached a set of proposals that both the auto and oil industries and the European Commission and Environment Council (Parliamentary Representatives) agree on. These include indicative emission standards for 2005, the original durability standards, and a cold start test. The proposed emission standards for Europe in the

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[65]Greenfield, P. 'Emission Improbable?' *Professional Engineering*, vol. 10, no.8, 30 April 1997, p.25.

year 2000 are as stringent or more so than the US Federal Standards.[66] These proposals are a mixture of cost-effective science and political compromise.

The details of the final directives are still speculation, as there are many views and suggestions among the numerous vested interests, and the scientific results of the Auto/Oil programme. There are also major splits among the European Parliament, partially related to the general wealth distribution mentioned previously. There seem to be two factions within the Parliament, one wanting faster change and compliance with cleaner, healthier air quality standards, and the second resisting change and the economic impacts it will bring.

The Future

Auto/Oil Stage 2 is now underway, and designed to make its proposals by 31 December 1998. It covers a variety of issues, building on the information and filling in the gaps exposed in Auto/Oil Stage 1. It is studying, among other issues, reducing gasoline sulphur levels to 50ppm, increasing vehicle fuel economy, implementing fuel performance incentives, developing an air conditioning cycle and the use of on-board diagnostics in diesel vehicles.

The first part of the European Auto/Oil Programme (as discussed in this paper) was a sound scientific investigation but it had very little political influence in the European Parliament or with the member states, as they had not been involved or included in any way in the process leading up to the presented results. Stage 2 of the Programme is concentrating on organizing the existing information from Stage 1 and elsewhere, into a useful (and politically acceptable) form in terms of legislation and implementation.

After Stage 2, there is a possibility of Stages 3 and 4, for long-term air quality aims. However it will be interesting to see if the auto and oil industries still feel this way after the resolution of the current debate and Stage 2.

Conclusions on the European Auto/Oil Programme

The European Auto/Oil Programme was, to a large extent, based on the US AQIRP Program and was designed to build on its information, considering the relationships between fuel, emissions and air quality in more depth. It also examined the effect of vehicle technology and non-technical measures,

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[66] Peake, S. *Vehicle and Fuel Challenges beyond 2000: Market Impacts of the EU's Auto/Oil Programme*, FT Automotive Publishing, London, 1997, p.1

such as inspection and maintenance programmes and traffic management schemes. It investigated US results which did not seem applicable to the European situation, due to differing air quality problems, differing base gasoline formulations or vehicle technology.

The stated objective of the European Auto/Oil Programme was 'to provide policy makers with an objective assessment of the most cost effective package of measures including vehicle technology, fuel quality, improved durability and non-technical measures, necessary to reduce emissions from the road transport sector to a level consistent with the attainment of the new air quality standards being developed for adoption across the European Union'. The programme provided a package of measures to reduce emissions from road transport but not enough to attain all the new air quality standards throughout the European Union. Athens, Madrid and Milan are predicted to fail to achieve at least some of the air quality standards, and will require more strict fuel, vehicle and non-technical measures and reductions in emissions from stationary sources.

The inter-industry test project and air modelling study were concerned with hard scientific fact, and although much of the work was done in secret, it does appear to have succeeded in this aim. The objectiveness of these parts could only be influenced by the parameters chosen for investigation, but this was avoided by selecting them through negotiation by the competing industries. The cost study has received more criticism concerning its objectiveness. The auto industry claimed it was biased against them as it looked at medium- to long-term effects, and they also claimed that the oil industry manipulated their fuel packages to be ineffectual and expensive.

Many of the criticisms of the European Auto/Oil Programme were similar to those made against the US Program upon which it was based. These include the assumption that test fuels and vehicles under laboratory conditions will give realistic results for an actual in-use fleet. They also assumed that all real fuels would be as clean and consistent as the test fuels, despite the fact that one of the original auto industry's complaints was that the advanced vehicle components could not cope with the current variability of European commercial fuels.

Some of the European test fuels, like the US, contained unusually extreme levels of certain components, which can lead to misinterpretation of the results due to undetected interdependent effects. This risk was less in the European Programme than the US, as there were fuels with intermediate parameter levels which would help illuminate certain errors in the trends.

The Europeans did pick up on some of the criticisms against the US Program, such as the use of doping agents that would never be found in gasoline under normal conditions. The European test fuels used a combination of compounds that simulated gasoline component behaviour.

Although the European Auto/Oil Programme was largely based on the US Program, I feel they could have benefited more from the US experience, especially considering the significant number of companies involved in both programmes.

The European programme was the more risky in terms of relations between the automotive and oil industries, as they tested both vehicles and fuels (the US focused on fuels only) in Phase I; and this meant they were, in a sense, competing for costs. The objectives, parameters and methodology for the European Research Programme, EPEFE, were negotiated successfully, despite conflicting wishes at several stages. This process makes the results more credible and therefore influential. It is a pity that when not working directly together the relationship between the two industries broke down somewhat.

The European Auto/Oil Programme's results were used to devise the European Commission's proposals on reducing air pollution through improving fuel quality and vehicle technology. These proposals are currently being debated within the European Parliament, and will involve some political compromise with the scientific basis of the Auto/Oil results. The final European law will then have to be implemented by the member nations of the EC. This legislation will probably differ from the original Auto/Oil results, but will have a basis in science rather than entirely political considerations as in previous legislation.

4. CONCLUDING COMMENTS

The US and European Auto/Oil Programmes had similar objectives and frameworks. They were both designed, in essence, to further knowledge about the relationships between fuels, vehicles, emissions and air quality and consisted of a testing project, an air modelling study and a cost study. The European Programme was started three years after the US one, and was largely based on it. Despite fundamental similarities, there were several major variations between the two programmes, motivated by differences in air quality, environmental priorities, existing fuel specifications and vehicle fleets.

Gasoline was common to both programmes as it is widely used in both the USA and Europe, and is therefore examined in much more detail in this paper. However other fuels were tested; 'alternative' fuels in the USA, where they have little market share but very influential backing, and diesel in Europe, where there is a significant diesel fuelled fleet and less alternative fuel production.

The gasoline parameters tested differed in the two programmes; the US Program briefly tested a broad range of chemical and physical properties of gasoline, whereas the European programme concentrated on three parameters, testing them in depth to determine the shape and more complex aspects of the fuel/emission relationships. Both programmes were built on existing information, but when the US one was initiated there was very little up-to-date, applicable information available, leading to a general investigation. The European Programme came later and had access to the initial US data, so they developed the information and adapted it to the European situation. The choices of parameters were also influenced by the environmental priorities and existing fuel composition.

Both programmes tested for emissions of nitrogen oxides, carbon monoxide, volatile organic compounds and hydrocarbons. The European Programme also tested for carbon dioxide, while the USA considered global climate change less important than their immediate urban air pollution. The nations of the EC view the threat of climate change with considerably more urgency than does the USA, so in this too differences in air quality motivated the differences between the programmes. Engine emissions of CO_2 are not significantly affected by changes in fuel or vehicle technology, although the emissions from the refineries are significantly increased by the gasoline reformulation process. Neither programme considered life-cycle emissions of the fuels (and the vehicles) would have to be taken into consideration if mobile source emissions are to be reduced.

The US test vehicles were intended to be representative of the current (to 1989) fleet, as they wanted immediate improvement through gasoline reformulation. The Europeans used a fleet representing probable millennium technology; their need was for a longer-term solution as their urban air problems were less severe.

The US Program measured exhaust, evaporative and running loss emissions, in contrast to the European which measured just exhaust and used the AQIRP (and other) data for non-exhaust emissions.

The air quality modelling and cost studies varied in more fundamental aspects than the testing programmes. The US modelled all the test gasolines to predict the improvement each one could have on the urban air quality. The European air quality modelling study only modelled a base case scenario for the current average gasoline, to estimate the necessary reductions in air pollution required to reach healthy concentrations. The US Program estimated incremental cost for producing the test fuels, compared to the European which estimated the cost-effectiveness of fuel, vehicle and non-technical measures. The USA intended to calculate cost-effectiveness but could not agree on a method, while the Europeans agreed on a method but had significant arguments over the execution and results.

The results of the two test programmes, although mostly not directly comparable, showed good agreement. The European results were more detailed and robust than the US ones, but fitted within the relationships seen in the latter, despite the different base fuels. The results of the air modelling and cost studies were not directly comparable, although the final recommended/proposed gasolines in both programmes had lower sulphur, lower distillation temperatures and higher evaporative temperatures. The European Commission proposals also included several points from the US Program, including lower RVP levels.

The Auto/Oil set-up of two industries, which are competing for regulatory cost, producing joint scientific information is unusual. It increased the credibility of the results and therefore the influence they held. The USA went one step further with independent experts overseeing a programme which was essentially run by extremely vested interests.

The Auto/Oil programmes showed that it was possible to provide sound technical data as a basis for regulation, allowing environmental control to work effectively and at least cost. The US Auto/Oil Program led to the regulation of a Californian reformulated gasoline, has been included in the EPA's air quality models for developing regulation and has resulted in the marketing of reformulated gasoline by various oil companies. The European Auto/Oil Programme was followed by European Commission Directives, which are currently being debated by various European bodies, and will be implemented by the year 2000.

The large-scale cooperation between two major industries demonstrated that it is possible to arrive at constructive solutions instead of shouting each other down to the regulator or legislator. It will be interesting to see whether these industries adopt this approach again.

Looking outside Europe and the USA, there is some evidence that the approach is spreading. In September 1996 Japan launched its own Auto/Oil Programme, entitled Japan's Clean Air Programme (JCAP) to be undertaken by the auto and oil industries and the Ministry of Technology and Industry. It consists of an inter-industry test programme, an air modelling study and a cost effectiveness study. The auto/oil story continues.

ANNEX 1: AIR QUALITY

The major air pollutants affecting human health include ozone, nitrogen oxides, volatile organic compounds (including aromatics), carbon monoxide and carbon dioxide, particulate matter and sulphur dioxide.

Ozone (O_3) is a powerful oxidizing agent, which when inhaled reacts with lung tissue and causes significant impairment of pulmonary function, coughs, nausea, lassitude and irritation to the eyes, nose and throat.[67] Its extreme reactiveness means it is harmful even at low concentrations, especially to asthmatics, children, and the infirm. It is not emitted directly from motor vehicles, but formed by nitrogen oxides and volatile organic compounds undergoing a series of photochemical reactions with sunlight (the ratio of volatile organic compounds to nitrogen oxides is thought to be as important to ozone formation as the overall quantity of emissions). Carbon monoxide also accounts for a significant amount of urban ozone formation. All three ozone precursors are produced in large quantities by road transport. Tropospheric ozone is the main constituent of photochemical smog and is currently the urban air pollutant causing most concern in the United States.

These precursors of ozone are also directly harmful to human health – nitrogen oxides through pulmonary impairment. Many volatile organic compounds are toxic, including aromatic hydrocarbons, such as benzene, which have been used in gasoline to replace lead and other pollutants, but are now causing concern due to their carcinogenic properties. Carbon monoxide (CO) decreases the human body's ability to absorb oxygen, and this impairs respiration, decreases cardiovascular efficiency and can have neurobehavioural effects.[68] Carbon monoxide is produced by incomplete combustion of gasoline in the engine and this is aggravated by a cold engine.

Other emissions of concern include sulphur dioxide (SO_2) and particulate matter under 10 micrometres (PM_{10})[69] and under 2.5 micrometres in diameter ($PM_{2.5}$). Although the direct risk to

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[67] World Health Organization, *Air Quality Guidelines for Europe,* WHO 1987, p.321.

[68] Ibid, p. 213.

[69] PM_{10} includes all particles which pass through a size-selective inlet with a 50 per cent efficiency cut-off at 10 μm aerodynamic diameter; Air Quality Report of the Auto/Oil Programme.

human health is now relatively low, sulphur dioxide causes acid precipitation and sulphur in fuel poisons catalytic converters, reducing their impact on other emissions[70] (which can be over a 99 per cent reduction in certain emissions). Sulphur dioxide is produced mainly from coal burning in industry and power stations and is not really seen as a transport emission. Particulate matter causes damage in the lungs and compromises respiration ability; it has no WHO guidelines as they were unable to find any level at which it did not harm human health.

Carbon dioxide (CO_2) has also received a lot of attention in recent years, as it is the main greenhouse gas and substantial increases in the stratosphere are thought to be causing global climate change; however it appears to be a lower priority in the USA.

All these pollutants have indirect impacts on human health, through effects on plant and animal life, water quality and other components of our environment.

The relationships between emissions and air quality are extremely complex as they are affected by many factors, including the distribution of sources, topography, climate, air current systems and seasonality.

Concentrations of nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOC) peak near their sources, especially at busy junctions and closed-in streets. Ozone, however, is a secondary pollutant and reaches its maximum levels downwind from the major sources, usually in the suburbs or rural areas.

Topography is very important as it affects whether a pollutant disperses or accumulates, and this is fundamental to the relationship between emissions and observed air quality. In the USA, the west coast cities are isolated by mountain ranges, and the Pacific Ocean which restricts the flow of air currents and encourages the pollution to accumulate. Humanity's tendency to build cities in topographic basins has also aggravated our pollution problems, as the isolated, sheltered nature of such areas prevents easy atmospheric mixing and dispersion, trapping the pollution within the basin. The topography of such basin cities, especially hot coastal ones, leads to frequent thermal inversions, trapping the emissions in a few tens to thousands of metres above street level. If the thermal inversion persists the accumulating pollution can reach harmful or fatal concentrations in densely populated urban areas. Los Angeles is a particularly severe example of a polluted basin city, surrounded by mountains on three sides and with the Pacific Ocean on the fourth; it suffers the worst pollution in

[70] Faiz, A. et al., *Air Pollution from Motor Vehicles,* The World Bank, 1996, p.183.

the USA.[71]

Road transport emissions are also significantly affected by the local climate, leading to seasonality and variations across the regions. Ozone pollution is much more severe during the summer, when the increased amount of sunlight encourages ozone formation and the higher temperatures increase the rate of ozone formation. Temperature inversions are also more common in the summer months, which keeps ozone's precursors (nitrogen oxides and volatile organic compounds) together at street level, and allows the formed ozone (and other pollutants) to accumulate. Carbon monoxide is more prevalent in the winter, when lower temperatures make vehicle engines burn more fuel less efficiently causing incomplete combustion and producing more carbon monoxide.

This effect is also seen across climatic regions. The northern and continental cities of the United States have more of a carbon monoxide problem and only occasional temperature inversions in the summer. The warmer, sunnier cities in the south have high ozone concentrations due to the intense sunlight, high temperatures and frequent episodes of pollution accumulation due to temperature inversions.

The situation is complicated further by pollution transportation which carries pollutants hundreds of miles in air currents. This effect was first recognized in an OECD study[72] in 1977, and led to the signing of the Convention of Long Range Air Pollution in 1979[73] by the USA and the European Community nations (and others). Ozone has a particularly strong transportation effect, as it has a very long half-life and is therefore effective for a long time (on an air-current timescale). This produces disproportionate amounts of ozone pollution in some areas, such as the so-called 'cancer alleys' in the mid USA[74] and severe problems in northeast USA. Other pollutants have a transportation effect but to a lesser extent as they are damaging to human health for a shorter length of time.

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[71]WHO/UNEP, *Urban Air Pollution in Megacities of the World,* World Health Organization, United Nations Environmental Programme, Blackwell, Oxford 1992, p.25.

[72] See Brackley, R., *Acid Deposition and Vehicle Emissions*, Policy Studies Institute & Royal Institute of International Affairs, 1987, p.4.

[73]See Nordic Council of Ministers, *Europe's Air, Europe's Environment,* Norstedts Tryckeri, Stockholm, 1986, p.86.

[74] MacDonald, G.J., 'This Common Inheritance – A Common View', *Energy & Environment,* 1991, vol.2, no.2, p.133.

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