UNITED
NATIONS

E

Economic and Social
Council

Distr.
GENERAL

EB.AIR/WG.5/1999/9
7 Avril 1999

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

EXECUTIVE BODY FOR THE CONVENTION ON
LONG-RANGE TRANSBOUNDARY AIR POLLUTION

Working Group on Strategies
(Thirtieth session, 31-May - 4 June 1999)

Item 2 of the provisional agenda

CONTROL TECHNIQUES FOR EMISSIONS OF VOLATILE ORGANIC COMPOUNDS (VOCs) FROM ROAD AND OFF-ROAD VEHICLES, AIRCRAFT AND SHIPS */

Introduction

1. The purpose of this document is to provide guidance to the Parties to the Convention in identifying VOC control options and technical and non-technical measures, including economic instruments, to enable them to reduce substantially the present level of emissions of pollutants from selected mobile sources, as stipulated in the Protocol.

2. It is based on options, techniques and non-technical measures for VOC emission reduction and their performance and costs contained in official documentation of ECE and its Inland Transport Committee, the Executive Body to the Convention and its subsidiary bodies, the International Civil Aviation

*/ Prepared by the Secretariat on the basis of comments submitted by Parties.

This document has not been formally edited.

GE.99-31251

Organization (ICAO), the International Maritime Organization (IMO), the Commission of the European Communities, the United States Environmental Protection Agency and on supplementary information provided by governmentally designated experts.

3. Unless otherwise indicated, these techniques and measures are considered to be well established on the basis of substantial operating experience and in some cases take into account the latest scientific advances in combating atmospheric pollution caused by gases emitted from mobile sources, which by the time the protocol enters into force will become fully operational and economically feasible in most Parties to the Convention as stipulated by laws, e.g. ECE regulations, European Union directives, the United States Clean Air Act, as amended in 1990, and the Canadian Vehicle Safety Act of 1997.

4. The choice of pollution control techniques and measures for any Party may depend on a number of factors, including legislative and regulatory provisions, existing refinery infrastructure, present vehicle fleet, etc., but in general they should be applied on a harmonized basis throughout the ECE region, if the emission reduction targets are to be achieved.

5. It should be borne in mind that mobile sources of VOC emissions are also sources of other pollutants, mainly NOx but also SOx and particles. In the choice of control options, all polluting emissions should be considered together and proven trade-offs fully taken into account, e.g. fuel VOCs and NOx, in order to find the most cost-effective combination of available control techniques and measures.

6. The document reflects the state of knowledge and experience of VOC control measures which had been achieved by 1998. As this knowledge and this experience continuously expand, particularly with new vehicles incorporating low-emission technology and reformulated and alternative fuels, the document needs to be updated and amended regularly.

MAJOR MOBILE SOURCES OF VOC EMISSIONS

7. Major mobile sources of anthropogenic VOC emissions include:

(a) Road vehicles:

- Passenger cars;
- Light-duty vehicles;
- Heavy-duty vehicles;
- Motorcycles and mopeds;

(b) Off-road vehicles and machines:

- Agricultural and forestry tractors and machinery;
- Industrial and construction machinery;
- Other engine applications such as lawnmowers, chainsaws, etc.;

(c) Aircraft:

(d) Navigation vessels:

- Ships and other marine craft;
- Inland waterway vessels;
- Outboard boats;

(e) Rail engines.

8. VOC emissions from these mobile sources and particularly from motor vehicles have been divided into:

(a) Tailpipe emissions;
(b) Evaporative and refuelling emissions; and
(c) Crankcase emissions.

9. Road transport (excluding petrol distribution) is a major source of anthropogenic VOC emissions in most ECE countries and contributes between 30 and 45% of total man-made VOC emissions in the ECE region as a whole. By far the largest source of road transport VOC emissions is the petrol-fuelled vehicle, which accounts for 80% of total traffic emissions of VOCs (of which 30 to 50% are evaporative emissions).

10. Evaporative emissions depend on climatic conditions, fuel properties and vehicle use patterns. Refuelling emissions result primarily from petrol use and depend to a large extent on its properties (aromatic, oxygen and benzene content). Evaporative and refuelling emissions from diesel fuels are very low. Their levels are similar to those of tailpipe VOC emissions from diesel-fuelled vehicles.

11. VOC emissions from off-road vehicles and machinery are important and account for 10% of national totals in the ECE region. Petrol-fuelled two-stroke engines are the largest single source category. The proportion of emissions from off-road vehicles will increase as emissions from road vehicles are gradually being reduced.

12. VOC emission estimates from shipping and air traffic are growing steadily. Although they are dispersed over large areas or air volumes, they contribute significantly to photochemical ozone formation.

13. Most ECE countries have enacted regulations that limit the emissions of pollutants from the mobile sources listed above, focusing primarily on road and off-road vehicles. Emissions from aircraft and ships are being regulated mainly by international organizations, e.g. ICAO and IMO, respectively.

14. Until other data become available, this document concentrates on road vehicles, off-road vehicles and machines, aircraft and ships, and contains techniques and measures to meet air quality objectives in the most cost-effective way derived from scientifically sound data.

ROAD VEHICLES

A. General aspects of control options and techniques for VOC emissions from road vehicles

15. The road vehicles considered in this document are passenger cars, light-duty vehicles, heavy-duty vehicles, motorcycles and mopeds. They may be equipped with positive-ignition engines and compression-ignition engines fuelled mostly with unleaded petrol, diesel fuel, liquefied petroleum gas (LPG), compressed natural gas (CNG) and biofuels, where appropriate.

16. This document deals with both new and in-use vehicles. It focuses on four main control options related to vehicle technology, fuel properties, programmes for enforcing durability and maintenance and non-technical measures, e.g. economically and environmentally efficient use of road space.

17. It also provides guidance on the influence of changes in petrol properties on evaporative and refuelling emissions, e.g. so-called reformulated petrol, and lists options for replacing conventional fuels by liquefied petroleum gas (LPG), compressed natural gas (CNG), ethanol, etc., which could be employed to reduce VOC emission. Fuel-volatility control is the single most effective measure that can be taken to reduce VOC emissions from in-use motor vehicles.

18. Vehicle technologies that incorporate catalytic converters with spark-ignited petrol engines require the use of unleaded petrol, which in most ECE countries is widely available. Moreover, the marketing of leaded petrol will be prohibited in the European Union (EU) from 1 January 2000 and phased out in the ECE region by 2010.

19. The use of after-treatment technologies in positive-ignition engines like catalytic converters and in diesel engines like oxidation catalysers and particle traps requires the use of low-sulphur fuel, maximum 0.05% S content, to avoid their premature degradation. Such fuel is available on the United States and Canadian market and in certain European countries. It has been agreed that both petrol and diesel fuel shall have a maximum sulphur content of 0.005 % from 2005.

20. It is important to ensure that emissions remain low in service and that vehicles are well maintained in use. This can be done by ensuring full useful-life durability, control in real-world conditions, conformity of production, recall of defective vehicles, warranty of emission-control components, and inspection and maintenance.

21. VOC emissions may be partly controlled by using clean fuels. Such fuel has enhancing properties, which means that it lowers the emissions from an existing vehicle, or is a fuel for which there is a dedicated engine concept, together reducing emissions. Reformulated conventional fuels, for instance, may be used in severe climate conditions and/or in a problem region/area. Clean-fuelled vehicles may be encouraged for fleets used in problem regions/areas.

22. Non-technical measures influence the management of long-distance and urban traffic, may protect sensitive areas, and play a role in reinforcing technical options and measures. They include, *inter alia*, efficient and

environmentally acceptable transport systems, traffic restrictions and economic instruments, mainly fiscal incentives. Their maximum estimated combined emission reduction potential, particularly for urban areas, is quite large. They also help to reduce other harmful effects of traffic expansion, such as noise and congestion, and improve road safety.

23. Cost figures for the various control techniques, if given, represent the costs of individual measures or components, but do not take into account the cost of combining these with automotive engines. They are expected production costs rather than retail prices, and do not take into account administrative and regulatory costs or social costs. Due to the fact that the same control technique may reduce different pollutants simultaneously, the indicated cost figures may also be attributed to other emission reductions than NOx.

24. The relationships between different control options or techniques, and particularly between engine technologies, fuel properties and exhaust emissions, are complex and may result in trade-offs between different pollutant emissions. This is especially true for petrol: with upgraded blends VOC emissions increase while those of NOx decrease or vice versa.

25. To cope effectively with such situations, computer-equipped vehicles are manufactured to be adaptive to a wide range of market fuel properties. Neither drivability nor emissions need be affected by a sudden fuel quality change. Vehicles lacking this control may be more sensitive to fuel properties, which would affect emissions. Diesel vehicles, for instance, tend to require more strictly controlled fuel to perform adequately.

26. The application of VOC control techniques also reduces in the same proportion emissions of toxic compounds, some of which are well known carcinogens. Reformulated fuel specifications may include such requirements, e.g. for benzene.

27. The aerosol emissions of lubricating oil from two-stroke engines such as motorcycles, mopeds, outboard engines, handheld tools, etc. are substantial and known to be toxic and carcinogenic. The cost-effective and efficient use of biodegradable oils for such applications can considerably reduce this problem, even for existing engines. The additional cost by use of biodegradable oils compared to conventional two-stroke oils is less than 5 US cents/litre of consumed fuel. This additional cost will decrease as demand increases. Mandatory use of biodegradable oils for two-stroke applications and/or important fiscal incentives for biodegradable oils, two-stroke engines should be considered as a configuration to solve the environmental problems of aerosol emission.

28. A variety of control options and techniques are available and can be mixed to control different pollutants simultaneously. However, their use should take into account well proven reverse and synergistic effects and their most cost-effective combination.

B. Control techniques for tailpipe emissions from road vehicles

Engine technology for petrol-fuelled passenger cars and light-duty vehicles

29. The main techniques for controlling VOC emissions are listed in table 1.

Table 1. Tailpipe emission control techniques for petrol-fuelled passenger cars and light-duty vehicles

Technology option		Relative VOC emission level to base	Estimated additional series production cost (DEM)
A.	Engine modifications (electronic control, EGR, single/multi-point fuel injection, auxiliary air injection).	800	N.A.
B.	Closed-loop three-way catalytic converter plus evaporative emission control.	100	0
C.	Advanced catalytic converter (trimetallic, close or under body, greater catalyst loading, heated catalyst)plus secondary air.	50-70	200-350
D.	Low-emission concept, integrated computer-managed control system (advanced EGR, improved-control) run on clean fuel with enhancing properties, for low lifetime tailpipe and evaporative emissions.	20-50	200-500

30. The reference technology for petrol-fuelled engines is option B, a three-way catalyser in a closed-loop configuration designed in response to the requirements of the 1990 amendments to the United States Clean Air Act and of the 1994 amendment to European Directive 70/220/EEC, corresponding also to ECE Regulation No. 83, 02 series. This technology achieves large reductions in emissions not only of VOCs, but also of CO and NOx.

31. In engine modifications, single-point injection and multi-point injection of petrol are the standard fuelling systems for emission control, offering an optimal air-fuel ratio distribution between cylinders, while dual-oxygen sensors (the addition of a second sensor after the catalytic converter) makes it possible to adjust the air-fuel ratio as required, thus improving the conversion efficiency of the catalytic converter.

32. In response to regulatory programmes for further VOC emission reductions (e.g. in Canada and the United States), advanced closed-loop three-way catalytic converters have been developed and implemented. Their features relate to different catalyst compositions, greater catalyst precious metal loading, close coupling of the catalytic converter, heated catalytic converters, etc.

33. The important operating catalytic converter parameters are warm-up and light-off time. The quicker catalytic converter warm-up can be achieved through several design features like the type of precious metal and its content, precious metals ratio and the location of the catalytic converter on

a front or rear brick. The most advanced trimetallic catalytic converters on ceramic support have a typical Platinum/Palladium/Rhodium ratio of 1:25:1. The installation of a light-off catalytic converter in addition to the main catalytic converter and secondary air injection can efficiently promote reduced catalytic converter off-time. Durability is a standing issue with design of faster light-off.

34. Engine and emission control system warm-up has great influence on total VOC emissions, particularly in a cold climate or when driving short distances only. Quick functioning of the control system is essential. VOC emission may otherwise be 10 times higher when driving at -7°C than at to +20°C.

35. Two-stroke engine cars are a special category. They have very high VOC emissions. However, their production in some parts of Europe has ceased and, subsequently, their use substantially decreased.

Diesel-fuelled passenger cars and light-duty vehicles

36. Table 2 summarizes available control technology options.

Table 2. Tailpipe emission control techniques for diesel-fuelled passenger cars and light-duty vehicles

Technology option		Relative emission level	Cost (DEM)
A.	Compression-ignition engine with indirect injection (IDI) or swirl combustion chamber and oxidation catalyst.	800	N.A.
B.	Engine modifications (DI or IDI engines, turbocharging and intercooling, EGR, electronic control, fuel injection management, etc.).	100	0
C.	Improved after-treatment; catalytic converted and/or particle trap, and/or CRT*/	50-70	200-350
D.	Low-emission concept, integrated computer-managed control system (advanced EGR, improved-control) run on clean fuel with enhancing properties, for low lifetime tailpipe and evaporative emissions.	20-50	200-500
*/ Continously regenerated trap (combination of particulate trap and oxidation catalyst)			

37. For diesel-fuelled engines, indirect injection with pre- or swirl combustion chamber is the most commonly used technology. When combined with electronic engine control providing for more precise fuel injection and metering, including the pressure at which the fuel is injected, they are also the most capable of achieving low emission levels as stipulated by the

reference laws at optimum cost.

38. The injection pressure of fuel is one of the key parameters relating to emissions from diesel engines. The higher the pressure, the better the atomization of the fuel, resulting in more efficient combustion and lower emissions.

39. Another engine design, the direct injection combustion chamber, is often associated with intercooled turbocharged concepts and with additional emission control devices like EGR, injection pump technology and oxidation catalysers.

40. The lower exhaust temperatures in diesel engines as compared to those fuelled with petrol limit catalytic converter light-off time and efficiency, especially at cold start in urban driving.

41. In response to future regulatory programmes for further VOC emission reductions beyond the year 2000 and 2005, more advanced emission control technologies will be required. They focus, inter alia, on engines having fully electronic systems, improved combustion control, higher cylinder pressures and particle traps.

42. The incremental costs of different changes related to vehicle technology with a potential to reduce emissions on average by 30 to 40% could add up to ECU 500, depending on the engine capacity, to the cost of a vehicle, or up to 3-4% of its present production cost. However, estimates for diesel vehicles are less certain than for petrol vehicles.

Engine technology for diesel-fuelled heavy-duty vehicles

43. Available control options for heavy-duty vehicles are almost the same as for light-duty ones. In addition to very high pressure fuel injection, turbocharging and charge air intercooling are standard concepts for all high-rated diesel engines. Therefore, the baseline engine configuration is option A. Moreover, all heavy-duty vehicle engines are direct injection diesel engines.

44. An oxidation catalyst will not remain efficient unless the fuel’s sulphur content is sufficiently low ~ 50 mg/kg. However, it is difficult to maintain an optimum operating environment for such a catalyst, which results in lower efficiencies of no more than 50 to 70%. The catalyst reduces the soluble organic fraction of the VOCs, leading to a lower particle mass.

45. Fleets, such as urban buses, may be equipped for alternative fuel use, e.g. gas of fossil origin (CNG) or biofuel. The cost of such a modification is high but can be offset by substantial reductions in pollutant emissions: up to 90% for VOC, NOx,CO and particles depending on the fuel considered.

46. The costs of control techniques for heavy-duty vehicles are higher than for passenger cars and light-duty vehicles, but if the amount of pollutants emitted and the kilometres travelled are considered then they are comparable.

47. The trend in developing further control technology for heavy-duty vehicles through the use of electronics, apart from variable pressure turbocharging, is similar for passenger cars and light-duty vehicles.

Motorcycles and mopeds

48. VOC emission control technologies for motorcycles are summarized in table 3. Current ECE Regulation No.40 can normally be met without reduction technologies. Austria’s and Switzerland’s standards require oxidizing catalytic converters for two-stroke engines in particular.

Table 3. Tailpipe emission control technologies and performance for motorcycles

Technology option	Emission level (%)		Cost (US$)*
	2-stroke	4-stroke	
A. Uncontrolled	400	100	-50350
B. Best non-catalyst	200	60	
C. Oxidizing catalyst, secondary air	30-50	20	
D. Closed-loop three-way catalytic converter	n.a.	10**	

* Additional production cost estimates per vehicle.
** Available for a few specific motorcycle types, mainly in Austria and Switzerland.

49. After-treatment technology is also available for motorcycles and mopeds. For two-stroke mopeds with small oxidizing catalytic converters, a VOC-emission reduction of 90% is achievable, at an additional production cost of US$ 30-50. In Austria and Switzerland, standards requiring this technology are already in force. EU is introducing the same requirements starting from 1999.

50. Motorcycle emissions of VOCs are highly dependent on driving patterns. Given their higher weight and load capacity, emissions from 3- and 4-wheelers tend to be high.

51. The fuel consumption and the resulting emissions from two-stroke motorcycles and mopeds can be substantially reduced, by 30 to 40% and by 80% respectively, by applying modern fuel-injection technology already successfully applied to two-stroke outboard engines.

C. <u>Controlling the performance of in-use vehicles</u>

Control of evaporative and refuelling emissions

52. Evaporative emissions consist of fuel vapour emitted from the engine and fuel system. They are divided into:

(a) Diurnal emissions, which result from the "breathing" of the fuel tank as it is heated and cooled over the course of a day and night;

(b) Hot-soak emissions produced by the heat from the engine after it is shut down;

(c) Running losses from the fuel system while the vehicle is in operation; and

(d) Resting losses such as from open-bottom canisters (where used).

53. The control technology typically used for evaporative emissions from petrol-fuelled vehicles includes changes related to the fuel system, e.g. improved pipework, connectors and fuel tank, a charcoal canister (and associated plumbing) and a purge system to burn VOCs in a controlled manner in the engine.

54. The single most cost-effective measure to reduce VOC emissions is to reduce volatility of in-use petrol. Therefore, effective evaporative emission control requires the consideration of:

(a) Control of petrol volatility, adjusted to climatic conditions; and

(b) An appropriate test procedure.

In general, evaporative emission control systems can provide the degree of control desired, especially during severe ozone-prone days, only when the volatility of in-use petrol corresponds to that of certification-test petrol.

55. The United States evaporative emission control programme resulting from the 1990 Clean Air Act amendments and that of Canada following the Vehicle Safety Act of 1997 have emphasized reduced-volatility fuels for use in summer and an improved test procedure to encourage advanced evaporative control systems that are expected to substantially improve the in-use control of the four emission sources mentioned in paragraph 50 above.

56. In the case of petrol- and also methanol-fuelled vehicles, the present evaporative emission standards set in the United States and Canada require that three tests be conducted: a three-diurnal plus hot-soak test, a supplemental two-diurnal hot-soak test and a running loss test.

57. A list of control options, reduction potentials and cost estimates are given in table 4, with option C as the best available control technology at present, representing a significant improvement over option B.

Table 4. Evaporative emission control measures and reduction potentials for petrol-fuelled passenger cars and light-duty vehicles

Technology option		VOC reduction potential (%)[1/]	Cost (US$)[2/]
A.	Small canister, lenient RVP[3/] limits, 1980s US Test Procedure	<80	202033
B.	Small canister, stringent RVP limits,[4/] 1980s US Test Procedure	80-95	
C.	Advanced evaporative controls, stringent vapour pressure limits,[4/] 1990s US Test Procedure[5/]	>95	

Notes:

1/ Relative to uncontrolled situation.
2/ Additional production cost estimates per vehicle.
3/ Reid vapour pressure.

4/ Based on United States data, assuming an RVP limit of 62 kPa during warm season at a cost of US$ 0.0038 per litre. Taking account of the fuel economy benefit associated with low RVP petrol, the adjusted cost estimate is US$ 0.0012 per litre.

5/ United States Test Procedure of the 1990s are designed for the more effective control of multiple diurnal emissions, running losses, operation under high ambient temperature, hot-soak conditions following extended operation, and resting losses.

58. The fuel economy benefits associated with evaporative emission controls are estimated at less than 2%. The benefits are due to the higher energy density, and low Reid vapour pressure (RVP) of fuel, and to the combustion rather than venting of captured vapours.

59. In principle, emissions that are released during refuelling of vehicles can be recovered by systems installed at petrol stations ?Stage II? or by systems on board vehicles, including in-use safety of on-board vapour recovery systems. Both controls are a well-established technology in the United States and Canada, and in certain European countries ?Stage II? has a 100% coverage.

60. ?Stage II? controls can be implemented more quickly since service stations in a given area can be fitted with these controls and benefit all petrol-fuelled vehicles, while on-board systems benefit only new vehicles.

61. A fuel dispensing spitback test may be conducted to control a vehicle’s refuelling emission control system.

62. While evaporative emissions from motorcycles and mopeds are at present uncontrolled in the ECE region, the same general control technologies as for petrol-fuelled cars can be applied.

Cleaner or reformulated fuels

63. The quality of fuels can have a significant impact on VOC emissions, primarily in relation to evaporative emissions and also as regards the use of catalytic converters. Cleaner or reformulated fuels have selected fuel parameter values that differ from conventional ones, but are still within their standard ranges. For petrol, the changes concern its volatility related to mid-range distillation (E-100), S content and aromatic content, while for diesel fuel they concern also S content, cetane number, polyaromatic content and residue (T95). Table 5 gives typical reformulated fuel parameter values.

Table 5. Selected typical parameters of reformulated fuels

Parameter	**United States**		**European Union**[2/]	
	Reformulated gasoline (RFG) Phase I	Oxygenated fuel (2.7 wt % oxygen)	Petrol	Diesel
RVP[1/]	7.2/8.1-S (8.7-S)[3/]	8.7-S	70/60 (kPa)	
Aromatics (vol %)	23.4 (28.6)	25.8	42/35 (40)	1-11
Benzene (vol %)	1.0-1.3 (1.6)	1.6	2.3/1.0	
Olefins (% v/v)			13/14-18	
Sulphur	302 ppm (338)	313 ppm	150/50 mg/kg (300 ppm)	350/50 mg/kg (450 ppm)
Oxygen (% m/m)		2.7	2.3/2.7	
Density (kg/m^3)				820/825-845
Cetane number				50/51
Lead			0.15 g/l[4/]	

Notes:

1/ Reid vapour pressure.
2/ .../... after 1 January 2000 and as from 2005.
3/ Conventional or base fuel parameters.
4/ The marketing of leaded petrol would be prohibited in the European Community from 1 January 2000, sales authorized up to 0.5% of total petrol sales and phased out in the ECE region by 2010.

64. Reformulated petrol (RFP), through its lower volatility, essentially aims at reducing VOC emissions, but to a lesser extent it also reduces the emissions of NOx and CO. This can be done by regulating the minimum oxygen content (2%) and the maximum benzene content (1%), increasing the oxygenates content, mainly ethanol and Methyl tertiary butyl ether (MTBE), controlled olefin content and introducing winter-time fuel requirements (up to 2.7% oxygen). RFP can achieve a 15 to 17% reduction in both ozone-forming VOCs and toxic emissions, i.e. 1.3 butadiene, from motor vehicles.

65. In general, reducing the S content in petrol lowers VOC, CO and NOx emissions especially with a warmed-up catalytic converter, and reducing aromatic content (particularly benzene) reduces VOC and CO emissions but increases NOx emissions. The latter happens due to the lower NOx conversion efficiency of the catalytic converter with low-aromatic fuels.

66. Diesel fuel may be improved by freeing it from sulphur, controlling density, lowering aromatics, while retaining high cetane number. VOC is affected by diesel density. Certain fuel formulas may be used in the existing fleet, while others require specific dedicated designs.

67. Discounted costs per litre of cleaner or reformulated fuels is ECU 0.011 for petrol and ECU 0.013 for diesel. The major cost of achieving

higher fuel standards is the capital cost of re-equipping refineries, which accounts for 60% of the total cost of their introduction on the market.

Programmes for enforcing durability and maintenance

68. In general, the rate of pollutant emissions increases as the vehicle ages. As a prerequisite for durable emission control systems or ?full useful life? of vehicles in terms of emission limits, monitoring programmes are needed under which manufacturers are responsible for recalling vehicles that fail to meet the required standards. To ensure that the owner has no production-related problems, manufacturers should provide warranties for emission-control components.

69. A relatively small number of very poorly maintained vehicles are responsible for most of the pollution from road vehicles. This explains the importance of carrying out programmes for enforcing durability and maintenance (I/M). They can reduce pollutant emissions by ensuring that vehicles have emission control systems in working order and comply with emission limits when in use. Well designed and enforced I/M programmes help to identify heavily polluting vehicles so that they can be repaired.

70. There should not be any devices to reduce the efficiency or switch off the installed on-board emission control systems during any operating conditions except when indispensable for trouble-free driving (e.g. cold start or during other specific conditions that make OBD monitoring particularly unreliable). It must be ensured that emission control systems are working effectively in all important real-life conditions, e.g. the United States and Canada and the new European Union cold start standard with specific emission limits for CO and HC.

71. The I/M programmes are complementary to monitoring programmes and should impose more robust engines and control systems. They should discourage vehicle owners from tampering with or disabling the emission controls, through direct enforcement, economic instruments and public information.

72. Inspections should verify that emission controls are in their original working order and that the rate at which the pollutant emissions increase, i.e. degradation, corresponds to the vehicle age and the I/M regime in place. In general, these effects are lower if the I/M regimes are more advanced.

73. In table 6 different I/M regimes are given. They correspond to the present practices in Europe, the United States and Canada. As a minimum requirement the Rules for periodical technical inspections of wheeled vehicles (commercial and large passenger vehicles) in international traffic established under the Agreement concerning the Adoption of Uniform Conditions for Periodical Technical Inspections of Wheeled Vehicles and the Reciprocal Recognition of such Inspection done at Vienna on 13 November 1997 should be considered.

Table 6. Typical in-use I/M options/regimes in Europe and North America

A.	Programmes to check the conformity of vehicles in circulation (1) Conformity of production (2) In-service compliance (recall)	
B.	Periodic roadworthiness tests (emissions + safety)	
	(1)	Uniform conditions for periodical technical inspections of wheeled vehicles (ECE/RCTE/CONF./4)
	(2)	Remote roadside sensing
	(3)	Enhanced short transient test cycle roadworthiness tests or remote roadside sensing of vehicle emissions
	(4)	Evaporative emission test
	(5)	Checking on-board diagnosis system (OBD)

74. I/M programmes can be beneficial for all types of control technology by ensuring that in-use vehicle emission levels are as close as possible to those of new vehicles. Additional repair costs can be offset by savings in fuel consumption.

75. The purpose of the on-board diagnostic system (OBD) is to ensure proper emission control system operation for the vehicle's lifetime by monitoring emission-related components and systems for deterioration and malfunction and to call the attention of the driver so that repairs are carried out. Its cost as undiscounted has been evaluated in Europe at up to ECU 100 per vehicle.

Non-technical measures

76. Non-technical measures with respect to long-distance traffic include different regulations promoting a shift from road traffic, both passenger and freight, to more environmentally-efficient modes of transport, such as rail, maritime, inland waterway and combined transport, through tactical, structural, financial and restrictive elements. Regulatory restrictions and incentives may lead to the use of less polluting vehicles and fuels, limit traffic and/or lower its volume and introduce road tolls and taxes, particularly in ecologically sensitive areas.

77. With respect to urban traffic, non-technical measures aim at better integrating land use and transport planning, gradually introducing cleaner vehicles and fuels and promoting ecologically-friendly mobility for optimal use of road space and environmental benefits. They may include traffic restrictions and alter personal mobility, e.g. parking policies, park-and-ride provisions to encourage commuters to use public transport and speed regulations, bringing into use extra-low polluting vehicles for delivery fleets, business cars, public bus and taxi services, limiting access to sensitive city areas and development of pedestrian and cycling facilities and infrastructure.

78. Some non-technical measures are of an economic nature and include road pricing in general, public transport subsidies, vehicle sales taxes, fuel taxes and scrap subsidies.

79. Non-technical measures, although not elaborated in this document, will be gradually developed within the Programme of Joint Action adopted at the Regional Conference on Transport and the Environment held in Vienna from 12 to 14 November 1997[1/].

CONTROL TECHNIQUES FOR EMISSIONS OF VOCs FROM MOBILE SOURCES OTHER THAN ROAD VEHICLES

I. OFF-ROAD VEHICLES AND MACHINES

A. General aspects of control techniques for off-road vehicles and machines

80. This chapter of the document considers all mobile or portable machines with combustion engines excluding passenger cars, light-duty vehicles, heavy-duty vehicles, motorcycles and mopeds. Emissions from ships and aircraft are discussed in chapters II and III below. Examples of such vehicles and machinery include agricultural and forestry tractors, construction equipment, lawnmowers, chainsaws, etc.

81. VOC emissions from off-road vehicles and machines are important and account for up to 10 per cent of national totals in the ECE region. Petrol-fuelled two-stroke engines are the largest single source category. The proportion of emissions from off-road vehicles will increase as emissions from on-road vehicles and stationary sources are reduced.

82. Estimating emission rates from some off-road sources can be time-consuming when the information required to compile the inventory is lacking. For machines the present market offers a wide variety of combustion engines. Advanced lists of emission factors for such engines are available e.g. Switzerland and United States.

83. Substantial progress has been achieved in the development of engine technology, exhaust gas and particulate after-treatment and fuel technology, making it possible to reduce VOC emissions from off-road vehicles and machines at reasonable cost. In addition, electrically powered alternatives exist for many applications.

84. It is important to ensure that new engine-emission standards are maintained in service. This can be done through inspection and maintenance programmes, ensuring conformity of production, full useful-life durability, warranty of emission-control components, and recall of defective vehicles and machines.

85. Enforcement, maintenance and inspection programmes for off-road vehicles and machines will be more difficult to implement than for road vehicles.

86. Fiscal and financial incentives will encourage the introduction of lower-emission technology.

87. Whatever measure is taken to either reduce fuel consumption or improve overall efficiency such as reduced weight, reduced air resistance or hydro-dynamic resistance, it will also reduce the resulting emissions.

88. Most emission reduction measures which are already well established for on-road engines can be transferred to off-road engines. These measures are described in paragraphs 15-76 above.

89. It is often easier to install reduction technologies in off-road units, as there are fewer space and weight restrictions.

B. Control technologies for VOC emissions from off-road vehicles and machines

90. State-of-the- art control technology options for off-road spark ignition engines are: evaporative controls, engine modifications (carburation, ignition systems, fuel injection, air injection), oxidation catalysts, open- and closed-loop three-way catalytic converters, cleaner fuels, etc.

91. State-of-the-art control technology options for off-road diesel engines are: improved combustion chamber design, exhaust gas recirculation, electronic engine management, improved injection systems and turbocharging and intercooling, oxidation catalysts, SCR, particular trap systems, humid air motor technique (HAM), cleaner fuels, etc.

92. Spark-ignited two stroke engines are a special category, as they have very high VOC emissions. Attempts are under way to apply engine modifications and catalytic after-treatment to this type of engine. Data are needed on the reduction potentials and durability of these solutions. Furthermore, different two-stroke engines that have significantly lower emissions have been and are currently being designed, based on direct injection and other improvements. In some applications, two stroke engines are being replaced by four-stroke ones.

93. Changes to the specifications of conventional fuels such as reducing petrol volatility and additions of oxygenates to petrol can reduce both evaporative and exhaust emissions of VOCs. In addition, the use of some alternative fuels in petrol and diesel engines can also reduce VOC emissions, especially the toxic components. Especially in the case of two-stroke engines e.g. chainsaws and lawnmovers the emission of toxic components like benzene can be very high. Today, for such machines special fuel qualities with much lower contents of benzene and other aromatics are available. Their use can reduce the emissions of benzene and other aromatics up to 98 %. Table (new) shows typical parameter values of such-low aromatic fuels for two-stroke and four-stroke engines.

Table 6. Selected typical parameter values of low-aromatic fuels for two-stroke and four-stroke engines

Parameter	Swedish norm (SS 15 54 61) and Swiss norm (SN 181 163)
Research octane number RON	min. 95
Density (kg/m3)	680-720
Sulphur content (%m/m)	max. O.002
Benzene content (%v/v)	<0.1
Aromatic content (%v/v)	<0.5
Lead content (mg/l)	2-5

94. Several after-tratment technologies such as catalytic converters and particulate trap systems are also suitable for the retrofitting of in-use machines.

II. SHIPS AND BOATS

A. General aspects of control technology for VOC emissions from ships

95. There are two major sources of VOC emissions from the maritime sector, whose relative importance varies from country to country depending upon geographical location and traffic density. These are emissions from pleasure craft (two-stroke outboard engines) and emissions stemming from the loading and unloading of volatile cargoes from tanker ships.

96. Emissions from pleasure craft can contribute up to 8% of national VOC emission totals. Control measures for such emissions are described in paragraph 89 above and can easily reduce the emissions by more than 80%. A number of ECE countries have already introduced regulatory measures to reduce emissions from smaller boats and pleasure craft, especially as inland waters are often used as drinking water reservoirs, in addition to other environmental concerns. EU is preparing a directive on pleasure craft engines.

B. Control technologies for VOC emissions from ships

97. Vapour recovery systems, both on board and at terminal, can reduce the emission by 98% and should be implemented according to the technical guidance developed by IMO in MSC/cirk 585 on Standards for Vapour Emission Control Systems.

98. Fiscal and financial incentives will encourage the introduction of lower-emission technology.

III. AIRCRAFT

A. General aspects of control technology for VOC emissions from aircraft

99. This document deals with all aircraft engines.

100. The limits on aircraft engine emissions of unburned hydrocarbons as contained in Annex 16, volume II, to the Convention on International Civil Aviation (the Chicago Convention) as may be amended from time to time, may be used for controlling the VOC emissions from turbo-jet and turbofan engines during landing and take-off (LTO) cycles within the Protocols to the Convention on Long-range Transboundary Air Pollution.

101. Only LTO emissions have so far been covered by the Protocols to the Convention on Long-range Transboundary Air Pollution with respect to emission inventories as part of national totals. Cruise emissions from domestic flights can also be considered as another part of national totals. Cruise level emissions may be more harmful. However, emission factors from the cruise phase are more uncertain than from LTO cycles. Studies have been initiated within ICAO on new emissions control parameters that would include cruise emissions.

102. Aircraft engines and aircraft with engines smaller than 26.7 kN/thrust are included in emission inventories but are not subject to international regulation at present. If they become subject to regulation, it should be borne in mind that an aircraft's lifetime is about 30 years and, therefore, new technology penetrates slowly. Retrofitting may therefore be considered when changing engines.

103. Emission-related levies, such as an en-route levy or a fuel levy, could encourage the introduction of lower-emission technology and are being studied by ICAO.

104. There is also scope for reducing fuel burn and hence emissions through improved operational measures such as more direct routings and implementation of communications, navigation, surveillance/air traffic management (CNS/ATM) systems.

B. Control technologies for VOC emissions from aircraft

105. State-of-the-art control technology for aircraft engine emissions encompasses fuel-air management optimization for existing engine types and two staged fuel combustion concepts for some emerging medium- to high-thrust subsonic aircraft engine types, which are beginning to enter into service.

106. Other combustion concepts such as lean/premixed/prevaporized (LPP) and rich burn/quick mix/lean burn (RQL) are being investigated for application to a second generation of supersonic aircraft engines. However, such engines are not expected to enter into service until at least 2006.

Endnote

1/ See document ECE/RCTE/CONF./3/FINAL.