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TECHNICAL DOCUMENT ON CONTROL TECHNIQUES FOR SELECTED MOBILE SOURCES [*]

Introduction

1. The purpose of this document is to provide guidance to the Parties to the Convention in identifying NOx and 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, technical and non-technical measures for NOx and VOC emission reduction and their performance and costs contained in official documentation of ECE and its Inland Transport Committee, the Executive Body for the Convention and its subsidiary bodies, the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), the Commission of the European Communities, the United States Environmental Protection Agency [1] and on supplementary information provided by governmentally designated experts.

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*/ Prepared by the drafting group at the thirtieth session of the Working Group on Strategies.

1/ Descriptions of the United States programmes in this document are merely illustrative. For details of national requirements see specific laws and regulations.

3. The document addresses the control of VOCs, as defined in article 1, paragraph 11, of the Protocol, and of NOx emissions considered as the sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2) expressed as NO_2. It lists a number of VOC and NOx reduction techniques and measures spanning a wide range of reduction potentials, costs and efficiencies

4. 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 Motor Vehicle Safety Act and Regulations of 1997.

5. 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.

6. It should be borne in mind that mobile sources of NOx and VOC emissions are also sources of other pollutants, for instance 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 NOx and VOCs, in order to find the most cost-effective combination of available control techniques and measures.

7. The document reflects the state of knowledge and experience of NOx and 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.

IMPORTANCE OF NOx and VOC EMISSIONS FROM SELECTED MOBILE SOURCES

8. Road transport is a major source of anthropogenic NOx emissions in the ECE region, contributing up to 60% of the total national emissions in some countries and even more in urban areas. Diesel-fuelled vehicles currently contribute most to road NOx emissions. Unless further measures are taken, NOx emissions from long-distance heavy-duty vehicle traffic and short-distance bus traffic will exceed the steadily decreasing emissions from passenger car traffic by the year 2000, due to the considerable growth in goods transport by heavy-duty vehicles, particularly in Europe.

9. Road transport (excluding petrol distribution) is also 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. VOC 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. NOx and VOC emissions from off-road vehicles and machinery are important and account for 10 to 20% of total NOx and VOC emissions in some countries of the ECE region. Diesel-fuelled engines and petrol-fuelled two-stroke engines are the largest single source category for NOx and VOC emissions respectively. The proportion of emissions from off-road vehicles will increase as emissions from road vehicles are gradually being reduced.

12. NOx and 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.

MAJOR MOBILE SOURCES OF NOx and VOCs

14. The main mobile sources of anthropogenic NOx 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 boats;
- Mobile drilling and production rigs;

(e) Rail engines.

15. 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 NOx and VOC emissions from road vehicles

16. The road vehicles considered in this document are passenger cars, light-duty vehicles, heavy-duty vehicles, motorcycles and mopeds. They may be equipped with spark-ignition engines or compression-ignition engines fuelled

mostly with unleaded petrol, diesel fuel, liquefied petroleum gas (LPG), compressed natural gas (CNG) or biofuels, where appropriate.

17. 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.

18. The document 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.

19. Vehicle technologies that incorporate catalytic converters with spark-ignition 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.

20. The use of after-treatment technologies in spark-ignition engines like catalytic converters and in diesel engines like oxidation catalysers reducing primarily CO and VOCs, selective catalyst reduction (SCR) to reduce NOx, and particle traps, requires only 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 in the European Union that from 2005 both petrol and diesel fuel will have a maximum sulphur content of 0.005%.

21. So-called reformulated fuels, mainly petrol, have been introduced on the market and are blended in such a way that, on average, they significantly reduce emissions of NOx, VOCs and air toxics, some of which are well known carcinogens, e.g. benzene, compared to conventional fuels. Such fuel, also called clean fuel, has enhancing properties, which means that it lowers the emissions from an existing vehicle, e.g, improved diesel fuel helps to lower emissions of NOx from in-use vehicles by up to 10%, or is a fuel for which there is a dedicated engine concept, together reducing emissions.

22. 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, significantly reducing for instance VOC emissions.

23. The aerosol VOC emissions of lubricating oil from two-stroke engines such as motorcycles, mopeds, outboard engines, hand-held 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 of using 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 should be considered to solve the environmental problems of aerosol emission.

24. 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.

25. 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.

26. 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. As the same control technique may reduce different pollutants simultaneously, the indicated cost figures may also be attributed to other emission reductions than NOx or VOCs.

27. The relationships among 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: NOx emissions increase while those of VOCs decrease or vice versa.

28. 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.

29. 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 effects and their most cost-effective combination.

B. Control techniques for NOx emissions from road vehicles

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

30. The main techniques for controlling NOx emissions from petrol-fuelled vehicles are listed in table 1, and for diesel-fuelled vehicles in table 2.

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

Option	Relative emission level [a]	Cost (EURO) [b]
A. Engine modifications (electronic control, EGR, single/multi-point fuel injection, auxiliary air injection).	500	N.A.
B. Closed-loop three-way catalytic converter plus evaporative emission control.	100	0
C. Advanced catalytic converter (tri-metallic, close or under body, greater catalyst loading, heated catalyst) plus secondary air.	50-75	100-175
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	100-250

a/ Compared to option A in per cent.
b/ Additional production cost compared to option B.

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

Option	Relative emission level [a]	Cost (EURO) [b]
A. Compression-ignition engine with indirect injection (IDI)or swirl combustion chamber and oxidation catalyst.	100	0
B. Engine modifications (DI or IDI engines, turbocharging and intercooling, EGR, electronic control, fuel injection management, etc.).	70	100-250
C. Engine modification (option B) plus advanced EGR, electrically or electronically controlled.	50	100-30
D. After-treatment: selective catalytic reduction (SCR) by use of catalyst agent or de- NOx catalyst).	20-40	75-100

a/ Compared to option A in per cent.
b/ Additional cost compared to option A.

31. 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.

32. 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 exhaust-gas recirculation (EGR) limits the formation of NOx, thus reducing their ?engine-out? emissions before any catalytic action.

33. The important operating catalytic converter parameters are warm-up and light-off time. Catalytic converter warm-up can be achieved more quickly 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 problem with the design of faster light-off.

34. For diesel-fuelled engines, the indirect injection and swirl combustion chamber are the most commonly used technologies.

35. 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 catalyser.

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

37. In response to future regulatory programmes for further NOx emission reductions beyond the year 2000 and 2005, more advanced emission control technologies will be required. They focus, inter alia, on advanced injection systems, close-coupled and under-body catalytic converter with different coatings and greater catalytic converter loading for petrol-fuelled vehicles and particle traps, de-NOx catalytic converters, selective catalytic reduction (SCR), and electronic engine control for diesel-fuelled vehicles.

Engine technology for heavy-duty diesel-fuelled vehicles

38. Table 3 summarizes available control technology options. To maintain the high efficiency and low fuel consumption, turbocharging and charge air intercooling are standard concepts for all high-rated diesel engines. Therefore, the baseline engine configuration is option A. Moreover, most heavy-duty vehicle engines are direct-injection diesel engines.

Table 3. Heavy-duty vehicle technologies, emission performance and costs

Option	Relative emission level [a]	Cost (EURO)[b]
A. Turbocharged direct injection compression ignition engine with intercooling.	100	0
B. Turbocharged compression ignition engine with intercooling, high-pressure fuel injection, electronically controlled fuel pump, combustion chamber and port optimization and EGR.	40-80	250-1500
C. Spark-ignition engine with three-way catalytic converter running on LPG and oxygenated fuels or modified compression-ignition engines running on CNG with three-way catalyser.	20-40	20000-25000
D. After-tratment for diesel engine: SCR by use of catalyst agent (or de-NOx-catalyst).	40	75-100

a/ Compared to option A in per cent.
b/ Additional production cost compared to option A.

39. 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 NOx, HC, CO and particles, depending on the fuel.

40. 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.

41. The trend in developing further control technology for heavy-duty vehicles is towards high-pressure injection systems, the use of electronics and advanced selective catalytic reduction.

Motorcycles and mopeds

42. Although actual NOx emissions from motorcycles and mopeds are very low (e.g. with two-stroke engines), they should be considered. While the VOC emissions from these vehicles are going to be limited by many Parties to the Convention, their NOx emissions may increase (e.g. with four-stroke engines). Generally the same technology options as described for petrol-fuelled passenger cars are applicable.

C. Control techniques for VOC tailpipe emissions from road vehicles

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

43. The main techniques for controlling VOC emissions are listed in table 4.

Table 4. Tailpipe emission control techniques for petrol-fuelled passenger cars and light-duty vehicles

Technology option	Relative emission level [a]	Estimated additional series production cost (EURO)[b]
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	100-175
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	100-250

a/ Compared to option A in per cent.
b/ Additional cost compared to option B.

44. 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.

45. 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.

46. 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.

47. The important operating catalytic converter parameters are warm-up and light-off time. Catalytic converter warm-up can be achieved more quickly 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 problem with the design of faster light-off.

48. 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 +20°C.

49. 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

50. Table 5 summarizes available control technology options.

Table 5. Tailpipe emission control techniques for diesel-fuelled passenger cars and light-duty vehicles

Technology option	Relative emission level[a/]	Cost (EURO)[b/]
A. Compression-ignition engine with indirect injection (IDI) or swirl combustion chamber and oxidation catalyst.	100	0
B. Engine modifications (DI or IDI engines, EGR, electronic control, fuel injection management, etc.).	70-80	100-250
C. Improved after-treatment; catalytic converter and/or particle trap .	50	150-300

[a/] Compared to option A in per cent.
[b/] Additional cost compared to option A.

51. 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.

52. 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.

53. 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.

54. 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.

55. 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.

56. 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 500 euros, 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

57. Available control options for heavy-duty vehicles are indicated in Table 6. 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.

Table 6. Control options for heavy-duty vehicles

Technology option	Relative emission level[a]	Cost (EURO)[b]
A. Compression-ignition engine with indirect injection (IDI) or swirl combustion chamber and oxidation catalyst.	100	0
B. Engine modifications (DI or IDI engines, turbocharging and intercooling, EGR, electronic control, fuel injection management, etc.).	70-80	100-250
C. Improved after-treatment; catalytic converted and/or particle trap.	50	150-300

a/ Compared to option A in per cent.
b/ Additional cost compared to option A.

58. 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.

59. 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.

60. 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.

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

Motorcycles and mopeds

62. VOC emission control technologies for motorcycles are summarized in table 7. 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 7. Tailpipe emission control technologies and performance for motorcycles

Technology option	Emission level (%)		Cost (EURO)[a/]
	2-stroke	4-stroke	
A. Uncontrolled	400	100	
B. Best non-catalyst	200	60	
C. Oxidizing catalyst secondary air	30-50	20	50
D. Closed-loop three-way catalytic converter	n.a.	10[b/]	350

a/ Additional production cost estimates per vehicle compared option B.
b/ Available for a few specific motorcycle types, mainly in Austria and Switzerland.

63. 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.

64. 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.

65. 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. Cleaner or reformulated fuels

66. The quality of fuels can have a significant impact on emissions, in particular 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 S content, mid-range distillation (E-100) and aromatic content. For diesel fuel, they concern also S content, cetane number, polyaromatic content and residue (T95). Table 8 gives typical reformulated fuel parameter values.

Table 8. Selected typical parameters of reformulated fuels in the European Union[*/]

Parameter	**Petrol**	**Diesel**
Vapour pressure (RVP) [a/]	60 kpa	
Aromatics (vol. %)	42/35 (40)	
Benzene (vol. %)	1.0 (2.3)	
Sulphur	150/50 mg/kg (300 ppm)	350/50 mg/kg (450 ppm)
Lead in unleaded petrol	0.005 g/l	

Notes:

*/ .../...: after 1 January 2000 as from 2005.
a/ Reid vapour pressure used between 1 May and 30 September.
b/ 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.

67. 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), controlling the 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, e.g. 1.3 butadiene, from motor vehicles and also smaller NOx emission reductions.

68. In general, reducing the sulphur content in petrol lowers VOC, CO and NOx emissions, especially with a warmed-up catalytic converter. Reducing the aromatic content decreases benzene, 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.

69. Diesel fuel may be improved by freeing it from sulphur, controlling density, lowering aromatics, while retaining high cetane number. NOx from in-use diesel vehicles may be reduced by using low-aromatic diesel fuel. Certain fuel formulas may be used in the existing fleet; others require specific dedicated designs.

D. Controlling performance of in-use vehicles

Inspection and maintenance

70. In general, pollutant emissions increase 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.

71. 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.

72. 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). It must be ensured that emission control systems are working effectively in all important real-life conditions, e.g. European Union cold-start standard with specific emission limits for CO and HC.

73. 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.

74. Inspections should verify that emission controls are in their original working order and that the rate at which the pollutant emissions increase, the 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.

75. In table 9 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 9. Typical in-use and I/M options/regimes in Europe and North America

A. Programmes to check the conformity of vehicles in circulation (CVC)

- (1) Conformity of production

- (2) In-service compliance

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) Checking on-board diagnosis system (OBD)

76. 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.

77. The purpose of the on-board diagnostic system (OBD) is to ensure proper emission control system operation during the vehicle’s entire 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 100 euros per vehicle.

Non-technical measures

78. 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 friendly modes of transport, such as rail, maritime, inland waterway and combined transport, through tactical, structural, financial and restrictive incentives. 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.

79. 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.

80. 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.

81. 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.[2]

CONTROL TECHNIQUES FOR EMISSIONS OF NITROGEN OXIDES AND VOLATILE ORGANIC COMPOUNDS FROM MOBILE SOURCES OTHER THAN ROAD VEHICLES

I. OFF-ROAD VEHICLES, MACHINES AND SHIPS

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

82. This section of the document considers all mobile or portable machines excluding passenger cars, light-duty vehicles, heavy-duty vehicles, motorcycles and mopeds. Emissions from ships and aircraft are discussed below. Examples of such vehicles and machinery include agricultural and forestry tractors, construction equipment, lawnmowers, chainsaws, etc.

83. NOx emissions from off-road vehicles and machines are important and account for 10 to 20 per cent of national totals in the ECE region. Diesel-

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

fuelled engines are the largest single source category. VOC emissions from off-road vehicles and machines are also important and account for up to 10 per cent of national totals in some countries of the ECE region. Petrol-fuelled two-stroke engines are the largest single source category.

84. The proportion of emissions from off-road vehicles and machinery will increase as emissions from on-road vehicles and stationary sources are reduced.

85. 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 market offers a wide variety of combustion engines. Advanced lists of emission factors for such engines are available (e.g. Switzerland, United States of America).

86. Substantial progress has been achieved in the development of diesel-engine, fuel and after-treatment technologies, making it possible to reduce NO_x emissions from off-road vehicles and machines at reasonable cost. Most emission reduction measures which are already well established for on-road engines can be transferred to off-road engines. They are described in paragraphs 16 to 81 above.

87. If NOx emissions are reduced by engine technologies, in particulate emissions may increase. This can be avoided by introducing particulate trap systems. State-of-the-art particulate traps can reduce the particulate mass by more than 90% and the particulate number by more than 99%.

88. 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.

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

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

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

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

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

93. 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, SCR, particulate trap systems, humid air motor technology, water injection, turbo compound, emulsified fuel, etc. If BAT without exhaust gas after-treatment is applied, the achievable lower limit for diesel engine emission is about 3.5 g NOx/kWh and 0.05 g particulate/kWh. For values beyond these limits after-treatment technologies and/or alternative fuels are required.

94. Many alternative fuels for diesel-engine applications have been proposed and investigated such as: methanol, ethanol, vegetable oils, compressed natural gas (CNG), liquefied petroleum gas (LPG), and dimethyl ether (DME). The last shows the lowest emission rates for NO_x and particulate matter.

95. Highly reformulated diesel fuels, such as the Swedish Class I fuel, can bring about modest reductions in NO_x emissions of the order of 5-10%.

96. According to the estimates available from international organizations, the additional investment costs required to develop new engines which meet stage I and stage II emission limits are 1400 euros and 2600 euros for 1 tonne of abated pollutants (of which two thirds are NOx emissions). Retail prices would increase by up to 3 per cent and up to 8 per cent for stage I and II respectively. In general, the marginal costs associated with developing new, cleaner engines are lower for larger engines.

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

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

98. 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.

99. 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.

100. 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.

101. 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 lawnmowers, the emission of toxic components like benzene can be very high. 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 10 shows typical parameter values of such low-aromatic fuels for two-stroke and four-stroke engines.

Table 10. 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. 0.002
Benzene content (%v/v)	<0.1
Aromatic content (%v/v)	<0.5
Lead content (mg/l)	2-5

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

C. General aspects of control technology for NO_x emissions from ships

103. The NO_x emission estimates from shipping are growing steadily and those from the North-East Atlantic alone are comparable to some larger countries' national totals. In some countries the emissions from inland waterways are also significant. Although maritime traffic emissions are dispersed over large areas, they contribute significantly to acidic deposition. National and international studies have clearly demonstrated the benefits of controlling marine NO_x sources compared to other major NO_x source categories.

104. The location of emissions from shipping (with respect to sensitive areas) and their contribution to acidification through long-range air pollution as well as local air pollution should be taken into account when defining control areas.

105. Uncontrolled ship diesel engines generate the highest NO_x emissions per unit of energy used. Unless control measures are applied to ships, their relative importance will grow within NO_x emission inventories as emissions from land-based sources are reduced progressively.

106. Reducing the sulphur content of fuel oil for ships has two possible benefits. The first is to reduce the direct impact of sulphur with respect to acidification. The second is to allow the use of cleaner, more environmentally sound engine technology and support the implementation of NO_x reduction after-treatment.

107. Due to the long lifetime of ship engines, marine NO_x emissions will decrease by only 1% per year, if measures to reduce NOx emissions by 30% as proposed by IMO in MARPOL Annex VI are applied only to new engines. To reduce emissions more rapidly, measures should also be applied to existing engines.

108. Fiscal and financial incentives encourage the introduction of lower-emission technologies and will continue to do so.

D. Control technologies for NO_x emissions from ships

109. The selected technologies for controlling NO_x emissions from diesel engines with a power output of more than 130 kW installed on ships are listed

in table 11. These include primary measures, after-treatment and fuel technology, and relate to both existing and new engines. Key figures concerning marine selective catalytic reduction (SCR) are given in table 12.

Table 11. Evaluation of selected technologies to reduce NO_x emissions from ships with diesel engines [a]

Measure	NO_x reduction	Remarks	Applicable to existing engines?	Availability
Engine internal measures (injection, swirl, etc.)	30%-40%	May cause penalty in specific fuel consumption and smoke	Conditionally yes	State of the art
Common-rail-injection	up to 30%		No	Available
Emulsified fuel or oil-water emulsion	30%	Visible smoke reduction	Yes, but reduction in power output	Available
Exhaust gas recirculation	10%-40%	Small penalty in specific fuel consumption	Conditionally yes	Available
Direct water injection	25%-50%	Requires clean water Fuel penalty	No	Available
Humidified charge air	55%-75%	Sea water can be used No fuel penalty	Yes	Under development and field testing
Selective catalytic reduction (SCR)	90%-98%	Also reduces hydrocarbons and particulates No fuel penalty	Yes	State of the art

a/ These measured are also applicable to other off-road diesel engines.

Table 12. Marine SCR in combination with oxidation catalyst - Key figures (1998)

NO_x reduction	95-99% at 10-100% maximum continuous rating (MCR)
HC reduction	75-95% at 10-100% MCR
CO reduction	20-50% at 10-50% MCR
PM reduction	0-50% at 10-100% MCR
Noise reduction	>25 dB(A)
NH slip	<5 ppmv at 95% NO_x reduction
Temp span	270-500°C (200°C)
Fuel	MDO, HFO (preferably low sulphur content 0.5-1.0%)
Weight	Silencer + 30%
Space	Same or smaller than silencer (30 dB(A)) Can replace silencer
Urea consumption	6 kg/MWh, at 10 g NO_x/kWh and 90% NO_x reduction
Urea solution	15 litres/MWh, at 40% solution
Typical lifetime	Between 20 000 and 40 000h before replacement of one catalyst layer, depending on the fuel quality

Note: The above-mentioned methods may be used in parallel to achieve the most cost-effective solution, e.g. matching of low NO_x engines in combination with SCR technique decreases the need for NO_x-reducing agents.

110. The appropriate technology should be selected for each individual case. There is no universal solution.

111. Emissions of NO_x from small petrol engines (e.g. outboard motors) are less significant than those from diesel engines but are expected to increase as four-stroke engines replace two-stroke ones in order to reduce volatile VOC emissions. This will be addressed by the coming EU directive on pleasure craft engines.

112. The sector of gas turbine applications for propulsion is growing. The NO_x emission problems must be addressed at the time of design.

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

114. Emissions from pleasure craft can contribute up to 8% of national VOC emission totals. Control measures for such emissions are described in paragraph 100 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

115. 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.

II. AIRCRAFT

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

116. This section deals with all aircraft engines.

117. The limits on aircraft engine emissions of oxides of nitrogen 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 NO_x 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.

118. 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 emission control parameters that would include cruise emissions.

119. Aircraft engines (other than turbo-jets and turbofans) and all 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 should therefore be considered when changing engines.

120. 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.

121. 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 NO_x and VOC emissions from aircraft

122. State-of-the-art control technology for aircraft engine emissions encompasses fuel-air management optimization for existing engine types (NO_x reduction potential of 10-20%) and two-staged fuel combustion concepts for some medium- to high-thrust subsonic aircraft engine types (NO_x reduction potential of 30-40%), which are beginning to enter into service.

123. 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. The target is a cruise NO_x level of 5g/kg of fuel burnt, which corresponds to a reduction of at least 80% of NO_x as compared to conventional combustion. However, such engines are not expected to enter into service until at least 2006.