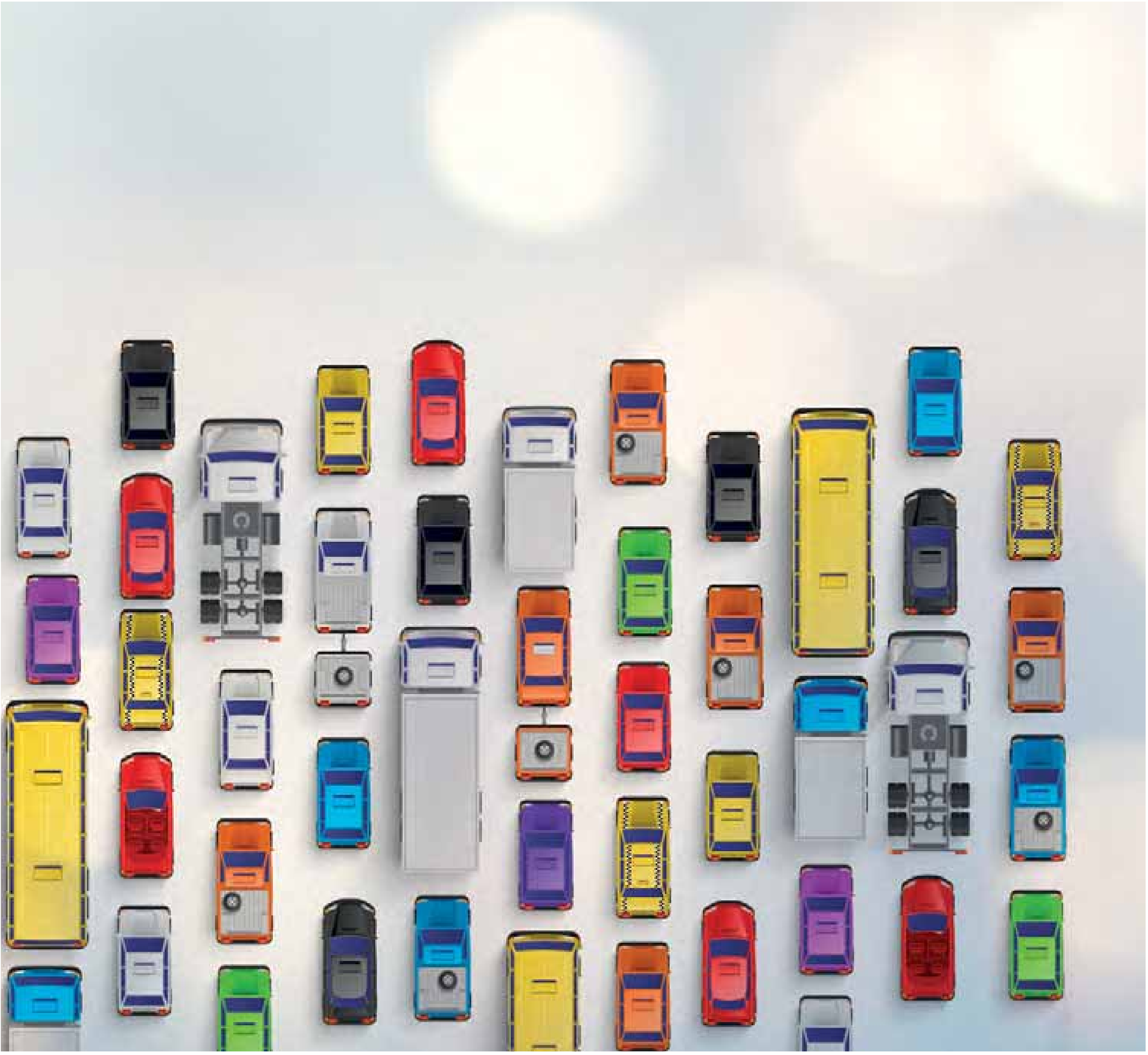
UNECE

ECONOMIC COMMISSION FOR EUROPE

Guidance Document on Emission Control Techniques for Mobile Sources under the Convention on Long-range Transboundary Air Pollution



UNITED NATIONS

UNECE

ECONOMIC COMMISSION FOR EUROPE

Guidance Document on Emission Control Techniques for Mobile Sources under the Convention on Long-range Transboundary Air Pollution

UNITED NATIONS

Note

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates a reference to a United Nations document.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

ECE/EB.AIR/138

UNITED NATIONS PUBLICATION
Sales No.: E.16.II.E.16
ISBN 978-92-1-117114-3
e-ISBN 978-90-1-058273-5

UNECE Information Service
Palais des Nations
CH-1211 Geneva 10
Switzerland

E-mail: info.ece@unece.org
Phone: +41 (0) 22 917 44 44
Website: www.unece.org

For more information, consult the Convention’s website:
www.unece.org/env/lrtap/welcome.html

Contents

List of abbreviations and acronyms

ASC	ammonia slip catalyst
BAT	best available technique
BC	black carbon
CCV	closed crankcase ventilation
CH_4	methane
CI	compression ignition
CNG	compressed natural gas
CO	carbon monoxide
DME	dimethyl ether
DOC	diesel oxidation catalyst
DPF	diesel particle filter
ECA	emission control area
ECE	United Nations Economic Commission for Europe
EGR	exhaust gas recirculation
GDI	gasoline direct injection
GHG	greenhouse gas
GPF	gasoline particle filter
HC	hydrocarbon
HDV	heavy duty vehicle
I/M	inspection and maintenance
LDV	light duty vehicle
LNG	liquefied natural gas
LNT	lean-NO_x trap
LPG	liquefied petroleum gas
LTO	landing and take-off
N_2	nitrogen gas
NECA	NO_x emission control area
NH_3	ammonia
NO_x	nitrogen oxides
NRMM	non-road mobile machinery
OBD	on-board diagnostics
PAHs	polycyclic aromatic hydrocarbons
PEMS	portable emissions measurement system
PFI	port-fuel injection
PM	particulate matter
$PM_{2.5}$	fine PM or ≤2.5μm in diameter
PN	particle number
POC	particle oxidation catalyst
ppm	parts per million
RDE	real-drive emissions
SCR	selective catalytic reduction
SECA	SO_x emission control area
SI	spark-ignition
SO_2	sulphur dioxide
SO_x	sulphur oxides
TWC	three-way catalyst
VOCs	volatile organic compounds

I. Introduction

1. The aim of the present document is to provide Parties to the United Nations Economic Commission for Europe (ECE) Convention on Long-range Transboundary Air Pollution with guidance in identifying the best abatement options for mobile emission sources, with particular reference to best available techniques (BAT), in order to assist them in meeting the obligations of the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol).

2. This document updates and replaces the guidance document on control techniques for selected mobile sources adopted in 1999 (see EB.AIR/1999/2). The technical background information and analysis that supports this updated guidance document is provided in a comprehensive technical report [1].

3. Emphasis is primarily given to techniques that can be implemented on each individual vehicle or engine concerned to reduce the emission rates over regular operation ("technical measures"). Other measures, including changes to fuel type or fuel specifications, as well as "non-technical measures", are also discussed. The latter include behavioural, operational, and infrastructural changes with the potential to reduce emissions.

4. This guidance identifies several techniques as BAT for reducing a specific pollutant. The proposed techniques have proven their potential for emission reductions in wide-scale real-world applications. Promising future techniques are also addressed. Identifying a technique as BAT for mobile sources by definition implies that the extra lifetime costs associated with its implementation are in proportion to its expected emission reductions. This accounts for the economic viability of the proposed technique. In addition, boundary conditions and limiting factors for the implementation of each technique have to be considered, as well as potential synergies and trade-offs on other environmental objectives. A BAT solution may consist of a combination of several individual techniques. Moreover, the probability that a technique is characterized as BAT increases when it has the potential to address more than one pollutant.

5. The definition of BAT for emission control of mobile sources is modelled according to the respective definition for stationary sources (see ECE/EB.AIR/117). In order to retain consistency, this guidance document does not attempt to provide an additional definition of BAT for mobile sources, but only to specify the criteria used for BAT selection in the case of mobile sources. On these grounds, a technique characterized as BAT for mobile sources possesses the following characteristics:

   - It provides measurable, real-world emission reductions over a reference technology at a cost that is in proportion to the reductions achieved;
   - It is technically feasible and has a proven record of implementation in actual wide-scale, real-world applications;
   - Any environmental or other side effects as a consequence of its implementation are greatly outweighed by the benefits obtained by the reduction of the pollutant(s) emissions it has been introduced to address.

6. Mobile sources, including non-road applications, comprise a diverse range of vehicles and machinery based on various concepts, operating under variable conditions and a multitude of environments. Consequently, the technologies implemented and the resulting emission levels may differ greatly between the different categories and applications. This document therefore provides recommendations per category of vehicle or machinery considered, and differentiates between BAT applicable for newer and older types. This makes it possible to account for differences in the vehicle fleet and mobile machinery stock structures encountered among Parties to the Convention. BAT applicability may well depend on a country's specific economic, environmental, and/or technological circumstances.

7. The recommendations in this document should be considered as general guidance on possible emission control techniques for the different mobile emission source categories. It is not an exhaustive list of all possible techniques. Under specific local conditions, other techniques might be judged equally good BAT candidates. Therefore, this guidance states for each BAT a number of limiting conditions. Additional limiting factors of a technical, financial or infrastructural nature may exist in particular cases.

II.
Coverage

8. This document addresses emissions of those pollutants considered in the Gothenburg Protocol, primarily nitrogen oxides (NO_x), volatile organic compounds (VOCs) and particulate matter (PM). Mobile sources are considered key categories in emissions of all those pollutants. A large percentage of PM emissions from mobile sources consists of black carbon (BC). Therefore, the techniques considered for PM reduction also address BC emissions.

9. Other pollutants considered in the Gothenburg Protocol include sulphur oxides (SO_x), ammonia (NH_3) and other ozone precursors, such as carbon monoxide (CO) and methane (CH_4). These pollutants are only addressed here when deemed relevant.

10. The majority of vehicles, vessels and other equipment operate on diesel and gasoline fuels. This guidance document suggests separate BAT per fuel, providing appropriate distinction between new vehicles and existing stock. It addresses both exhaust and non-exhaust emissions (evaporative, component wear) and includes technical and non-technical measures. Technical measures include powertrain, fuel switching, and after-treatment technologies. The following table summarizes the main categories of mobile sources considered for emission control techniques in this document.

11. ***Mobile sources not included in the Gothenburg Protocol:*** Annex VIII to the Gothenburg Protocol does not include emissions from the following mobile sources: aircraft, seagoing ships (short sea or deep sea), and (electric) trams, metros and trolleybuses. However, emissions from some of these sources are either included in the national inventories in the framework of the Convention (aircraft landing and take-off (LTO) phases, domestic shipping) or there are considerations on how to include them (international maritime). As for electric trams, metros and trolleybuses, although they do not have tailpipe emissions, they produce heavy metal emissions due to the wear of their components and, in particular, sparking that occurs in the power lines. For these reasons, all these mobile sources are also briefly covered in this guidance document.

Main categories of mobile sources considered:

	Spark-ignition engines	Compression ignition engines
Road vehicles	Mopeds and motorcycles Light duty vehicles (passenger cars, light commercial vehicles)	Light duty vehicles (passenger cars, light commercial vehicles) Heavy duty vehicles (trucks, buses)
Non-road mobile machinery (NRMM)	Handheld and non-handheld equipment (household, gardening, agricultural and forestry machinery)	Industrial, construction, agricultural and forestry machinery/tractors Railcars, locomotives
Inland waterways	—	Compression ignition engines (passenger ships, freight vessels)

III. Emission processes and contributions

12. Mobile sources emit air pollutants primarily as the product of the combustion of fuels in their engines. Engine measures related to combustion efficiency and control of fuel properties can lead to reduction of these emissions. Further reductions can be achieved by the use of after-treatment devices in the exhaust line. Component wear (tyres, brakes) and gasoline fuel evaporation from the tank of road vehicles are the most common sources of non-exhaust emissions (i.e., in the form of PM). These emissions are also addressed in the present document.

13. Mobile sources contribute about 40 to 60 per cent of all NO_x emissions and about 10 to 30 per cent of all fine particulate matter ($PM_{2.5}$ or ≤2.5µm in diameter) emissions in the different parts of the ECE region (year 2010). The largest single emission sources are diesel-powered cars and trucks, followed by agricultural tractors. Diesel-powered rail and shipping activities also constitute a significant source of emissions in some Parties to the Convention. Mobile sources contribute about 20 per cent of all VOCs emissions in the different parts of the ECE region (year 2010). The biggest single mobile sources of VOCs are gasoline-powered light duty vehicles, including two-wheelers, followed by smaller machinery and agricultural machines. Land-based mobile sources contribute less than 1 per cent to total sulphur dioxide (SO_2) emissions and 1 to 4 per cent of total NH_3 emissions in the different parts of the ECE region (year 2010).

14. Due to the significant contribution of mobile sources to NO_x and PM emissions, these two pollutants receive most of the attention in this guidance document. VOCs and NH_3 emissions are dealt with only for those mobile sources that significantly contribute to their total emissions and when well-established and economical techniques can be used to achieve substantial emission reductions. Emission levels usually increase with the age of mobile sources, as the effectiveness of emission control degrades with time. Furthermore, malfunctions, which can be due to misuse, fatigue, or stochastic faults, may also degrade emission control.

IV. Best available techniques for emission control from mobile sources

15. This section provides specific recommendations for emission reduction per mobile source category based on the assessment of BAT candidates. For each category, the proposed measures are divided into those for new vehicles/engines, in-use vehicles/engines (existing stock), and future vehicles/engines (prospective or promising emerging technologies). Common issues for the assessment and selection of BAT, related to all mobile source categories, include: (a) (limitations in) the applicability of a technique to new or existing vehicles/engines; (b) the environmental benefits and costs (retrofit/manufacturer costs); (c) implementation issues; and (d) environmental side effects, synergies and trade-offs (impact on fuel consumption, unregulated pollutants, etc.). In general, the techniques implemented by the manufacturers to meet the latest emission standards are considered BAT for the vehicles and machinery types currently produced (considered as new ones). Limitations in applicability and implementation issues are of particular importance in the assessment process and include technological barriers, infrastructural needs, environmental conditions, fuel specifications and maintenance requirements.

A. Mopeds and motorcycles

16. Gasoline-powered mopeds and motorcycles have traditionally been significant emitters of VOCs and CO. In particular, mopeds in the past have been powered mainly by two-stroke engines, which have been notorious emitters of unburned hydrocarbons and, because of this, PM as a result of piston scavenging losses. Historically, the contribution of these vehicles to urban air pollution has been increasing, especially in densely populated (urbanized) areas of the world that rely on mopeds and motorcycles as an essential means of transportation.

1. BAT for new vehicles (typical exhaust emission control and fuel evaporation control)

17. The technologies used to meet the latest emission limits, considered as BAT for new vehicle types, are mainly port-fuel injection, stoichiometric combustion (i.e., controlled by a lambda sensor) and catalytic exhaust after-treatment. Catalyst technology ranges from simpler design oxidation catalysts (e.g., on mopeds and small motorcycles) to control CO and hydrocarbons (HC), up to three-way catalysts with closed-loop air/fuel ratio (on the largest four-stroke engines). In these cases the emission control technology is similar to that used in gasoline passenger cars.

18. Often, combustion in mopeds and some motorcycles (mainly of smaller size) is adjusted to the slightly rich side to enhance performance and responsiveness. In these cases, secondary air is injected in the exhaust port before the exhaust reaches the catalyst. The overall mixture may be off stoichiometrically, but the catalyst effectively reduces CO and HC, while NO_x are suppressed in the cylinder by the rich combustion. Depending on the catalyst and the tuning, some further NO_x reduction in the exhaust line is possible.

19. ***Two-stroke engines:*** Although recently there is a trend to phase out two-stroke engines because of the VOCs emission problems, vehicles with this engine type are still in production. In order to meet the new emission limits, significant investments in emission control are needed. This includes electronically controlled fuel injection directly in the cylinder for precise metering of the quantity and timing of the fuel supplied, and secondary air injection in the exhaust line and oxidation catalyst to control HC emissions and, secondarily, CO, while NO_x need to be controlled primarily by combustion calibration measures. The new components and the controls of the package make the two-stroke lose some of its edge regarding simplicity, cost and power-to-mass ratio, compared with four-stroke engines.

20. ***Fuel evaporation control:*** Evaporative emissions control on motorcycles consists of carbon canisters connected to the fuel system. Low permeability tanks are also used, similar to passenger cars. Evaporation control is only applicable to larger vehicle types, but it is expected to be extended to all vehicle types in the future.

2. BAT for the existing stock (in-use vehicles)

21. The existing stock of mopeds and motorcycles is a good candidate for emission reduction measures, especially targeting the old two-stroke engines and vehicles without after-treatment control. However, the small displacement engines used in the majority of existing vehicles complicates emission control issues due to space limitations and the simple design characteristics of small engine technology. Hence, for vehicles without after-treatment control, retrofitting a catalytic converter in general cannot be recommended as BAT. The only option that can be considered as an effective measure for the older existing stock is to focus on removing those vehicles from the road; such measures, i.e., accelerated replacement schemes boosted by financial incentives, are by far the most effective approach in reducing urban air pollution. For motorcycles of more recent technology (newer existing stock), which are probably equipped with a catalyst, the following techniques are proposed as BAT options.

22. ***Emission control system maintenance:*** Emission control system failures and malfunctions can be identified by inspection and maintenance schemes. A programme requiring annual inspections of all two-wheel vehicles is recommended and should consist of measuring vehicle emissions and requiring repairs when specified le els are exceeded.

23. ***Fuel and lubrication oil of good quality:*** Catalyst deactivation may be caused by impurities in the fuel and lubrication oils. For two-stroke vehicles, in-cylinder addition of lube oil magnifies this problem. Hence, enforcing the use of manufacturer-recommended oils rather than cheap alternatives, as well as lube oil changes at recommended intervals, can be considered as BAT for existing engine types.

3. Assessment of alternative fuels considered for gasoline replacement in two-wheelers

24. Use of alternatives fuels (e.g., liquefied petroleum gas (LPG) or compressed natural gas (CNG)) without further (after-treatment) emission control does not offer substantial improvements in terms of air quality (see more detailed discussion on gasoline cars). In addition, there are significant safety and space limitations for storage of such fuels on board the motorcycle. Hence, in general, alternative fuels cannot be considered as BAT for gasoline replacement in mopeds and motorcycles.

4. Future vehicle types

25. ***Gasoline vehicles:*** The Euro 4 and Euro 5 standards already set very demanding targets, requiring advanced emission control technology. Specifically, for motorcycles it is expected that three-way catalysts and stoichiometric combustion will be extensively used, while for mopeds larger catalysts and overall better engine strategies will be necessary. Especially for the Euro 5 standard it is expected that significant technological breakthroughs will be required, such as improved quality and packaging of the whole system (stoichiometric combustion with three-way catalyst (TWC)). Cost and space limitations may be a limiting factor in smaller vehicles, i.e., mopeds, since closed-loop control of the TWC will be required, as well as positioning of the catalyst close to the engine outlet (or dual-layer exhaust line) for fast light-off, twin lambda sensors for long-term performance verification of the emission control devices, etc. The whole package is expected to significantly increase the end price of mopeds; this, combined with the trend towards replacing two-stroke with four-stroke engines, is expected to result in much more competitive larger vehicles in terms of value for money. Moreover, the stringent standards are expected to further accelerate the phasing out of two-stroke engines.

26. ***Electric vehicles:*** Electric two-wheelers have the potential to provide significant air quality benefits and such vehicles have started to become popular in several markets recently. Challenges in terms of weight and space constraints need to be addressed. In any case, a wider penetration of electric mopeds and motorcycles is to be expected in the future when the technology and cost-competitiveness of batteries improves and this could lead to reduced vehicle weight for the same driving range requirement. Electrification has a real future potential as BAT for mopeds and motorcycles.

B. Spark-ignition (gasoline) on-road light duty vehicles

27. In a spark-ignition (SI) engine, fuel with high vapour pressure is mixed with air and the combustible mixture is ignited by a spark plug to produce power [2]. SI (gasoline) engines have traditionally been the most popular propulsion system for passenger cars, but they are also used (to a smaller extent) in light commercial vehicles. Gasoline-powered vehicles significantly contribute to the total VOCs emissions, while their contribution to NO_x and PM is lower than their diesel counterparts.

1. BAT for new vehicles (typical exhaust emission control and fuel evaporation control)

28. The latest emission standards are met by emission control measures that include both engine and after-treatment technologies and are considered as BAT for new vehicle types. There are two main combustion concepts for gasoline engines with distinct characteristics. The most widespread one is the so-called port-fuel injection (PFI), while the second concept is the gasoline direct injection (GDI) engine. Because of their distinct (and different) performances, these two concepts are considered separately.

29. ***PFI engines:*** For emission control, PFI engines are calibrated stoichiometrically and combined with a closed-loop TWC. Typically, the exhaust system also includes an upstream oxygen sensor that monitors the oxygen content of the exhaust and continuously adjusts the fuelling to match the operation conditions. A downstream oxygen sensor is used to monitor the oxygen storage capacity of the catalyst and, by this means, its real-world performance. Over the years this typical configuration has proved to be very efficient and may lead to the lowest emission levels of all conventional vehicle technologies today for all regulated pollutants.

30. ***GDI engines:*** GDI is a more recent technology of SI engines introduced to improve fuel efficiency and power output by directly injecting fuel into the cylinder. Today, most of the GDI engines operate stoichiometrically over their complete operation range, but engines that combine both modes (lean and stoichiometric combustion) in different load regions are also available. Stoichiometric GDI NO_x emissions do not substantially differ from conventional PFI vehicles. However, partial lean-burn GDI engines are prone to high NO_x emissions because of oxygen availability in the exhaust. A lean-NO_x trap (LNT) can be used in these lean applications to reduce NO_x. Because of engine control limitations and sulphur intolerance, not many commercial applications of such a concept (lean operation with LNT) are available today. GDI vehicles may also lead to increased PM (and particulate number (PN)) emissions. These can be controlled by a modified injection strategy and an improved fuel system. Gasoline particle filters (GPFs) are also an effective technology to reduce particulate emission, with high filtration performance under all engine operation points and ambient temperature variation, if engine measures alone are not enough.

31. ***Fuel evaporation control:*** Non-methane VOCs originating from the vehicle's fuel system (evaporative emissions) occur as a result of fuel volatility combined with the variation in ambient temperature and the temperature changes in the fuel system of the vehicle. The activated carbon canister is an essential component of the evaporative emission control system and it is used to trap vapours in the vent line of the fuel tank. Low permeability tanks are also used to control evaporative emissions. They reduce the permeability of plastics and polymers to gasoline in either the liquid or vapour phase.

2. BAT for the existing stock (in-use vehicles)

32. The majority of gasoline light duty vehicles (LDVs) on the road today are already equipped with TWCs in Western European and North American countries. A well-maintained TWC-equipped gasoline vehicle is generally considered a low emitter, although some exceptions may exist due to adverse operating conditions, like extreme temperatures. Therefore, the focus of a BAT approach for such vehicles would be to maintain their good overall performance. In regions where a significant percentage of non-catalytic vehicles are still in operation, efforts focusing on removing such vehicles from the road are by far the most effective approach in reducing air pollution. Experience shows that accelerated replacement schemes boosted by financial incentives are very effective in removing those old vehicles from the road [3] [4] [1]. The following two techniques are proposed as BAT options for TWC-equipped (in-use) vehicles.

33. ***Emission control system maintenance:*** The emission reduction effectiveness of the catalyst may be severely degraded over time due to a variety of reasons. Emission control system failures and malfunctions can be identified by inspection and maintenance schemes. Techniques involving remote sensing of emissions coupled to number-plate recognition can be very effective in identifying high emitters. Traditional periodical simplified tests need to be enhanced to be more effective (e.g., including measurement of NO_x levels). Finally, onboard diagnostics (OBD)-related failure identification techniques can be an additional option for more recent vehicle technologies. Once a malfunction has been identified, maintenance may include component replacement (e.g., catalyst), recalibration, or cleaning (e.g., injectors). Replacement of old catalysts identified by inspection is expected to have a significant impact not only on the three main pollutants (CO, VOCs and NO_x), but also to have a very positive side effect on NH_3 emissions, since aged catalysts reduce NO_x more efficiently than NH_3.

34. ***Fuel evaporation control:*** Despite some technical difficulties, retrofitting activated carbon canisters and low permeability tanks can be considered as BAT to reduce evaporative emissions. Moreover, since no inspection techniques exist for the efficiency of the canister and no manufacturer maintenance schedule includes canister replacement, developing and including such tests in regular inspection programmes may be a very effective policy. Replacing the canister can be considered a BAT for older vehicle types.

3. Assessment of alternative fuels considered for gasoline replacement in two-wheelers

35. Alternative fuels offered for spark-ignition vehicles, such as natural gas, liquefied petroleum gas and bioalcohols, are often promoted as "clean" alternatives to conventional fuels. When compared to gasoline, most alternative fuels offer limited or no net emission improvements. In several cases, alternative fuel use may lead to the reduction of a specific pollutant, but it might also result in the increase of other toxic, but unregulated, pollutants. In addition, retrofits of existing vehicles to run on alternative fuels entail the risk of increased emission levels owing to the often limited technical sophistication of the retrofit technology and the lack of efficient mechanisms to verify the quality of the retrofit and the resulting emission level in the real world. Hence, in general, alternative fuels cannot be considered as BAT with regard to regulated pollutants for gasoline replacement in road vehicles. This in principle means that emission reductions achieved by any of these fuels can also be achieved by an improved gasoline combustion and after-treatment system as well. Ongoing scientific research and regulatory efforts in the production and promotion of alternative fuels mainly stem from energy security considerations (e.g., natural gas) and the need to reduce greenhouse gases (GHGs) from transport. In any case, fuel changes for spark-ignition vehicles need to consider changes in the emission profiles of both regulated and unregulated pollutants, as well as the possibilities to verify the real-world emission performance of modified vehicles.

4. Future vehicle types

36. ***Gasoline vehicles:*** TWC will continue to be the main component for emission control in the future. Advanced TWCs are designed and produced with better catalyst layering and formulation, while engine calibration is further enhanced. The most significant changes are expected for GDI vehicles with regard to the upcoming more stringent Euro 6c PN limit, which is expected to require the use of a GPF (possibly combined with a TWC) for several vehicle types. Engine measures may also be used to achieve PM and PN GDI Euro 6c limits, i.e., high-pressure spray-guided multi-injection with advanced piezoelectric injectors. For NO_x control, either stoichiometric combustion with a TWC or lean-burn with an LNT can be used. Further to the more stringent control of exhaust emissions, future gasoline vehicles will also be more strictly regulated in terms of their evaporation emissions, as indicated by the revision of the relevant European legislation which is currently under way [5]. This revision aims to improve the control of evaporative emissions in real-world driving conditions.

37. ***Hybrid and electric vehicles:*** Gasoline hybrids primarily aim at reducing energy consumption and GHG emissions, but studies have shown that some of them can also achieve impressive reductions in air pollutants. They have started to become very popular in several markets in the ECE region. Battery and fuel cell electric vehicles are also advanced technology vehicle types with the potential to achieve significant GHG and air pollutant emission reductions in the future.

Currently, all these concepts have penetrated the market in various (small) degrees [6], depending on the concept, due to various limitations (technical, economic, infrastructural). Especially for electrics, a significant real-world penetration can only take place when the technical and cost competitiveness of batteries improves and when the limiting factors for the proliferation of hydrogen power systems (safe, economical and clean production and distribution of hydrogen) are addressed.

C. Compression ignition (diesel) on-road light duty vehicles

38. In a compression ignition (CI) engine, fuel is self-ignited after the pressure and temperature inside the combustion chamber rise by compression [2]. CI engines used in road applications are fuelled mainly with diesel fuel and, in general, produce high NO_x and PM emissions. The latter include a large percentage of BC and are associated with elevated PN emissions.

1. BAT for new vehicles (typical exhaust emission control)

39. In terms of engine measures, a typical diesel engine for a new vehicle utilizes high-pressure multi-pulse common rail injection, multi-valve cylinder heads and exhaust gas recirculation (EGR). The approach for after-treatment NO_x control varies for different models, including: (a) control of NO_x with engine measures only (no NO_x after-treatment); (b) utilization of an LNT; and (c) selective catalytic reduction (SCR) with urea injection in the exhaust line. A diesel particle filter (DPF) is used to control PM and PN levels within regulatory limits.

40. It should be mentioned that, up to the firs generation of Euro 6 vehicles introduced in 2014, real-world operation NO_x emissions have been reported at a much higher level than the corresponding emission limits. In-use conditions cover a much wider operation range than the type-approval driving cycle does. Emission control in such off cycle conditions relaxes to the benefit of fuel economy. In order to decrease NO_x emissions over a wider operational range, engine and after-treatment systems need to be recalibrated. In particular, the EGR map will have to be widened in terms of engine speed and load and/or urea injection will have to be increased in SCR systems. Finally, better thermal management may be required so that after-treatment devices reach optimum conditions faster after the first switch-on of the engine. Relevant tests have shown that the combination of engine measures, EGR and SCR can lead to real-world NO_x levels that respect Euro 6 limits over a wide operation range.

2. BAT for the existing stock (in-use vehicles)

41. The existing stock of diesel LDVs is a good candidate for emission reduction measures because, in particular for NO_x, those vehicles have been shown to substantially exceed their corresponding type-approval limits in real-world operation [7] [8]. This is the result of the tuning of the emission control systems to deliver emission reductions only within the operation boundaries of the type-approval driving pattern.

42. However, the options to control emissions from such vehicles, in particular the older stock, are limited. Emission control systems retrofits (e.g., SCR) encounter technical difficulties and limited space availability, which make their wide-scale application difficult to achieve in practice (e.g., such as a municipal retrofit programme). For vehicles using more recent technology (newer existing stock), several of the available emission control technologies do have the potential to lead to significant emission reductions, even in real-world operation, when properly calibrated or retuned to improve their functioning. Regarding the possibility to use alternative fuels as a diesel replacement, only renewable diesel can lead to realistic (but rather moderate) emission reductions. Although other fuels (e.g., natural gas) could theoretically offer some reduction, they cannot be recommended for widespread use on existing vehicles due to the excessive modifications required and various limitations (technical, financial, etc.), as well as low emission reduction effectiveness (biodiesel).

43. Given these considerations, the range of emission reduction measures for existing stock diesel LDVs is restricted mainly to the following non-technical ones.

44. ***Access restrictions and/or complete removal from roads:*** Restricting the access of diesel LDVs to city centres and the enforcement of environmental zones can offer significant environmental benefits. In regions with a significant proportion of diesel cars, efforts focusing on removing such vehicles from the road provide by far the most effective approach for reducing urban air pollution.

Experience shows that accelerated replacement schemes boosted by financial incentives are very effective in removing particular vehicle types from the road and replacing them with cleaner vehicle technologies. In the case of diesel LDVs, such a measure could assist in replacing diesel vehicles with gasoline, natural gas, or other cleaner vehicle types.

45. ***Inspection and maintenance:*** Current periodic tests usually do not include NO_x tests and are not reliable enough for detecting broken DPFs. Hence, they need to be developed further in this respect. OBD-enabled identification techniques seem reliable. However, currently they will at best be relevant for PM controls; as long as NO_x emissions in real-world driving are high by design, OBD will not signal malfunction.

3. Future vehicle types

46. ***Typical diesel emission control:*** A combination of EGR, with a diesel oxidation catalyst (DOC), SCR (or LNT for smaller vehicles) and a DPF is expected to constitute the default emission control system for future diesel LDVs. Real-drive emissions (RDE) testing for diesel NO_x emissions is expected to require a new calibration of and control strategy for the whole system; monitoring the performance of the various components by means of OBD will guarantee efficient long-term performance. Although no provisions on ammonia slip control for Euro 6 cars have been made in the regulations yet (as is the case with heavy duty vehicles (HDVs)), it can be stated that an ammonia slip catalyst (ASC) (downstream of the SCR catalyst) is necessary to avoid ammonia slip when SCR is used. This may require further uptake in regulations.

47. ***Alternative fuels and powertrains:*** CNG can be used as a diesel replacement in the future, not only because of the emission reductions it can achieve, but also because it is seen as diversifying the energy mix and, hence, reducing dependence on oil. Second generation biofuels are currently under investigation, but there is not much information yet on the emission benefits that those fuels can offer apart from their GHG savings. For diesel hybrids, the market potential looks promising.

D. Compression ignition (diesel) on-road heavy duty vehicles

48. Similar to LDVs, so far compression ignition engines in HDVs have been fuelled mainly with diesel fuel and, in general, produce high NO_x and PM emissions. Furthermore, crankcase emissions of older engines also contribute to VOCs and PM emissions.

1. BAT for new vehicles (typical exhaust emission control)

49. The latest emission standards are met by emission control measures that include both engine and after-treatment technologies and are considered as BAT for new vehicle types. Key engine measures include EGR, high pressure injection with precise fuelling control and optimized air exchange processes. After-treatment consists of a combination of a DOC for CO/HC control, SCR for NO_x control, a DPF for PM control and an ASC to eliminate excess NH_3 emissions produced by the SCR operation. Both Euro 6 (European Union) and US2010 (United States of America) standards require such advanced emission control measures to regulate emissions within the emission limit levels for HDVs.

2. BAT for the existing stock (in-use vehicles)

50. Existing HDVs are good candidates for emission reduction measures. Especially for vehicles owned by public authorities or belonging to captive fleets (e.g., urban buses, refuse trucks), implementation of measures such as retrofits and fuel changes can be realized. The following BAT recommendations can be considered for existing HDVs.

51. ***SCR and DPF retrofits:*** Retrofitting exhaust after-treatment devices is a cost-effective technique that can achieve significa t environmental benefit . Especially SCR (for NO_x) and DPFs (for PM) appear to be best available techniques for emission reduction from existing HDVs. SCR and DPFs can be implemented together for a combined positive effect on both NO_x and PM with potential cost advantages (as compared with implementing them separately). Several examples around the world have demonstrated successful retrofits of NO_x and PM control systems in both long-haul trucks and urban buses.

52. ***Other retrofits:*** DOCs can be implemented in combination with DPFs and SCR. As a stand-alone retrofit, it can be considered as BAT, especially in large-scale applications, being more tolerant to fuel sulphur than a DPF, and when other technical factors (e.g., regeneration possibilities) exclude the applicability of DPFs. Closed crankcase ventilation (CCV) retrofits can be considered as BAT to control crankcase emissions of older vehicles. If left to openly vent to the atmosphere, the crankcase from an old diesel engine can contribute up to 25 per cent of total VOCs (and PM) emissions, hence, a CCV retrofit can contribute to total emission reduction. A CCV can be combined with a DOC or a DPF. EGR on the other hand has limited potential due to technical difficulties integrating this on existing engines.

53. ***Fuel switching:*** Conversions to natural gas (most frequently in compressed form) are possible (e.g., in urban buses), but difficult to implement due to technical complications (in particular with regard to the storage tanks) and high initial costs. Among other fuel possibilities, only renewable diesel can deliver measured, yet moderate, reductions, primarily to PM. Alternatives such as dimethyl ether (DME) and emulsified diesel are currently not recommended due to various technical, financial, or other limitations. DME in particular seems to have a promising future, once cost issues related to its production are solved. First generation biodiesel has low emission reduction effectiveness in blending levels currently allowed by regulations. Second generation biofuels may have the potential for cleaner combustion, but this remains to be proven for specific market fuels.

54. ***Hybridization:*** Replacement of an old HDV with a new hybrid one can achieve some emission reductions with additional (significant) fuel consumption benefits. Hybridization can be considered as BAT, especially for buses in urban applications. In addition to their contribution to overall city-level emission reductions, urban buses have the advantage of reducing the exposure of passengers as they queue in bus stops and/or as buses take off from the bus stop. The key limitations for hybrid buses include the high initial capital cost, although fuel efficiency improvements may lead to cost benefits in the long run. Also, questions still exist on the long-term performance of the hybrid system batteries. Hybrid trucks are not in mass production yet.

3. Future vehicle types

55. ***Typical diesel emission control:*** A combination of EGR, a DOC, SCR and a DPF is expected to constitute the default emission control system for diesel HDVs in the future. Further optimizations of the system and monitoring of the performance of the various components by means of OBD will guarantee the efficient long-term performance of the various subsystems.

56. ***Alternative fuels and powertrains:*** DME may have the potential for diesel replacement in the future (effectively addressing PM and simplifying NO_x control), but the issues of production and distribution need to be addressed first. Other alternative renewable fuels can also constitute possible future BAT candidates for long-haul trucks. Concerning the use of alternative powertrains, certainly a wider diversification is to be expected, especially in hybrid urban buses, possibly combined with an alternative fuel (e.g., natural gas) for additional emission reductions. Fully electric buses may also be a possibility as fast or wireless charging systems start to become available. There are also some small fleets of prototype hydrogen fuel cell buses already operating in different parts of the world [9], but the proliferation of hydrogen technologies can only be achieved if the production and distribution of hydrogen become economically competitive. Long-distance trucks are unlikely to significantly benefit from hybrid powertrain concepts, but developments for delivery trucks are ongoing.

E. Particulate matter from component wear and abrasion from road vehicles

57. PM from component wear and abrasion contribute significantly to total PM emissions [10]. Related measures to improve air quality should tackle both primary emissions (new dust material produced) and resuspension of dust (already accumulated on the road), as vehicles pass by [11]. For example, street sweeping has produced mixed results in reducing resuspension, but does not address primary emissions at all.

58. ***Measures for abatement:*** On the basis of the current limited practical experience and evidence, the following measures can be considered to reduce the negative effects of wear dust [12]: (a) minimizing the sources (e.g., by adjusting pavements and gritting material; using coarser, wear-resistant rock aggregates; using alternative pavements; adjusting tyres (increased wear resistance); and avoiding the use of studded tyres); and (b) minimizing dispersion to air (however, experience so far on tests with, inter alia, wet roads and dust binding materials, is limited). In addition, traffic measures, such as reducing traffic activity, decreasing the share of trucks and calming traffic could also assist in both minimizing the sources of wear dust and its dispersion to air. Gentle braking (and acceleration) also produces less wear.

59. ***Brake measures:*** Brake wear is due to forced deceleration of road vehicles during which brake linings are subject to large frictional heat generation. Brake (as well as tyre) wear may release toxic heavy metals. A measure that can be considered for emission reduction is to change brake composition (e.g., ceramic brakes have fewer emissions). A brake particulate collection system was also recently developed that recuperates particulates generated by brake shoes. Regenerative braking has also become increasingly widespread in late-model vehicles. With this system, mild to moderate braking is achieved by the resistance of a generator coupled to the wheels. This recuperates part of the kinetic energy to charge the battery of the vehicle and hence improves fuel economy. The system has, as a positive side effect, the reduction of brake pad wear.

F. Gasoline engines in non-road applications

60. Non-road gasoline engines are a highly diverse category, including handheld and non-handheld equipment (household, gardening, agricultural and forestry machinery) over a range of sizes and power outputs [13] [3]. The main pollutants of concern emitted by engines of this category are VOCs and CO [14]. VOCs are the result of incomplete combustion and scavenging losses, mostly due to the widespread utilization of two-stroke engines in this category. There are also concerns with regard to PM emissions from such engine types (excess hydrocarbons). These are mostly a concern for those immediately exposed to their exhaust, such as the operator.

1. BAT for new engines (typical emission control)

61. Emission control in non-road gasoline engines is less advanced than in on-road applications because of limiting factors, including space, maximum operation temperature, noise and limited total lifetime. Often these engines are required to operate in various position angles. Because of their high power-to-weight ratio and the lack of a lube oil carter, two-stroke engines are ideal in this category.

62. Emission control for this category mostly focuses on reducing scavenging losses from two-stroke engines. Techniques used in this respect include improved combustion and mixture exchange control for two-stroke engines (direct injection, compression wave injection, stratified scavenging, etc.). Those are the most widespread techniques used in the smaller engines applied in handheld machinery, such as chain saws. A different strategy involves replacement of two-stroke by four-stroke engines, in particular for larger ground-supported machinery, such as lawnmowers or compactors. Replacement of gasoline-driven engines by electric-driven engines could form another good alternative for certain applications (e.g., lawnmowers).

63. Emission control by catalytic after-treatment is less frequent in small gasoline engines of this category (than in larger gasoline engines) and is limited by a number of factors. The operation of the engines with fuel-rich mixtures to control exhaust gas temperature limits the efficiency of oxidation after-treatment. Furthermore, oxidation catalysts can increase the exhaust gas temperature above comfortable or permissible levels. Therefore, catalytic control is used on special machinery only.

2. BAT for the existing stock (in-use engines)

64. The special character and emission control practices of non-road gasoline engines calls for individual techniques in order to attempt to address emissions from the existing stock. Hence, the following measures correspond to BAT for this particular engine category.

65. ***Replacement:*** Machinery in this category can have a very short lifetime (fi e to six years) and is of relatively low cost. Therefore, replacement of the complete item with a younger generation one can be considered BAT in this case, considering that the new equipment will comply with the latest emission limits.

66. ***Lubrication oil of good quality:*** Use of good quality (approved by the manufacturer) and low additized (e.g., calcium-free and sulphur-free) lubrication oil is important, in particular for two-stroke engines, and increases the efficiency and long-term performance of any catalytic after-treatment possibly used. Sophisticated lubrication is essential to allow lubrication of the engine in multi-position tools (hedge trimmers, chainsaws, cut-off machines); therefore, good quality lube oil becomes increasingly important, regardless of the existence or not of a catalyst. Enforcing the use of manufacturer-recommended oils rather than cheap alternatives can be considered BAT for existing engine types.

67. ***Aromatic-free (alkylate) gasoline:*** Start-up and normal (hot) operation emissions can be reduced by using gasoline that is free of aromatics, benzene and olefins. Such fuel is called "alkylate gasoline" due to its high content in branched paraffins (alkylates). Moreover, the rather simplistic fuel system of small engines results in relatively elevated fuel evaporation; the use of aromatic-free and benzene-free gasoline therefore reduces the polycyclic aromatic hydrocarbons (PAHs), benzene and other toxic (including mutagenic) content of pollutants liberated with evaporation.

3. Future engines

68. New engine types that are designed to fulfil the next step of emission control (Stage III) standards may benefit from the following more advanced technological solutions.

69. ***Combustion improvements:*** Four-stroke technology will continue to proliferate and is expected to appear for smaller engines as well. Hybrid engines — where lubrication is similar to two-stroke (via the combustible mixture), while combustion occurs in four strokes to eliminate scavenging losses — have also started to appear. Stratified scavenging, where air containing less fuel drives the exhaust out of the two-stroke cylinder, is also a concept for two-stroke engines.

70. ***Evaporation control:*** Evaporation losses are significant contributors to total VOCs emissions from engines of this category. This is mainly due to the rather simplistic fuel system of small engines that allows increased fuel evaporation. Therefore, use of low-permeability tanks and fuel lines is a BAT to reduce evaporative emissions. While the technology to control emissions is available and regulations in the United States call for evaporation control, such requirements have not been adopted in European regulations yet.

G. Diesel non-road mobile machinery and rail

71. Diesel NRMM is a mobile source category that generates environmental problems similar to on-road HDVs, i.e., high NO_x and PM emissions, and VOCs (and PM) from the crankcase emissions of older engines. Emissions of NRMM are of particular concern in environmentally sensitive environments, e.g., tunnels, mines, etc.

1. BAT for new engines (typical exhaust emission control)

72. The latest emission standards are met by control measures that constitute BAT for new engines. A typical configuration of a Stage IV/Tier 4 emission control system comprises a direct-injection diesel engine with turbocharging and intercooler. EGR may be present in some applications, but SCR is usually sufficient to achieve the NO_x emission reductions required. An ASC may also be used to oxidize any excess NH_3 and avoid slipping above the regulatory limit of 25 parts per million (ppm). For PM control, DOCs or particle oxidation catalysts (POCs) are usually used. Wall-flow DPFs are generally not necessary to achieve Stage IV/Tier 4 limits.

2. BAT for the existing stock (in-use engines/machinery)

73. NRMM has a long lifetime and, because of this, several technical measures can be considered to reduce emissions from the existing stock. The following BAT recommendations can be considered for the existing stock.

74. ***SCR and DPF retrofits:*** After-treatment retrofits for diesel NRMM is a current practice that usually has very good results in terms of reducing emission levels, provided that efficient retrofit equipment with type approval is being used. SCR (for NO_x control) and a DPF (for PM control), or a combination of the two, are current practices that can significantly reduce emissions, which is important to achieve for equipment used in sensitive environments (tunnels, mines, etc).

75. ***Other retrofits:*** DOCs can be implemented in combination with DPFs and SCR. As a stand-alone retrofit, it can be considered as BAT, especially in large-scale applications, being more tolerant to fuel sulphur than a DPF, and when other technical factors (e.g., regeneration possibilities) exclude the applicability of DPFs. CCV retrofits can be considered as BAT to control crankcase emissions of non-road diesel engines and it can be combined with a DOC or a DPF. EGR on the other hand has limited potential due to technical difficulties in integrating this measure on existing engines.

76. ***Fuel switching:*** Among the alternative fuels that can be used, only renewable diesel is suggested for existing engines. However, the reductions that can be achieved are only moderate. Other fuels, such as natural gas, DME and emulsified diesel, while offering some emission reductions and/or GHG benefits, cannot currently be recommended for widespread implementation due to various technical, economic, or other limitations. First generation biodiesel has low emission reduction effectiveness in blending levels currently allowed by regulations.

77. ***Hybridization:*** Replacement of old NRMM equipment with new hybrid equipment can achieve some emission reductions with additional fuel consumption benefits. However, the technology is not yet in mass production and the experience is very limited. In any case, it has the potential to be further established in the future for some engine categories (e.g., port handling equipment). Current applications have had mixed results both with regard to pollutant emissions and fuel consumption, very much depending on the match between the hybrid operating strategy and the duty cycle. The main limitations of this source category relate to purchase price premium, payback and return of investment, real fuel economy and competing technologies.

78. In addition to the above techniques for emission control of the existing stock, repowering (i.e., simply replacing the existing engine with a new one) can also be an effective strategy in certain cases. Because of the long useful lifetime of some NRMM equipment, repowering can provide the opportunity to install a new engine (or a new engine equipped with exhaust emission controls) that meets much lower emission standards than the original engine, often in conjunction with fuel economy benefits and lower maintenance costs. Repowering is particularly common for old diesel locomotives (engine replacement by generator sets) and can be extended to other machinery types, in particular when the engine comprises a relatively low percentage of the total cost of the machinery (e.g., cranes).

3. Future engines/machinery

79. ***Emission control for diesel concepts:*** The major update expected in upcoming Stage V [15] is the introduction of wall-flow DPFs to control PM and PN. In principle, this is expected to bring emission control on par with the latest on-road Euro 6 emission stage. In-use recording of emissions using a portable emissions measurement system (PEMS), included in the regulation, will guarantee the efficiency of the emission control during normal operation. Other enhancements in the emission control may include more widespread implementation of EGR, SCR optimization, and the possible combination of SCR and a DPF in the same component.

80. ***Alternative fuels and powertrains:*** It is certainly more difficult for alternative fuels and powertrains to penetrate the NRMM (than the on-road vehicle) market, since diesel combustion is by far preferable for such engine types owing to its high efficiency, durability and torque characteristics. In any case, the concepts that may have a potential in the future are natural gas, DME and hybrid engines in specific applications (e.g., port handling equipment). Currently, the experience regarding all of these is very limited.

H. Diesel vessels (inland waterways)

81. Diesel vessels and engines are among the transport equipment with the longest lives, with lifetimes that may exceed 30 years. Moreover, only a very small percentage of them are scrapped and replaced every year. Therefore, control measures addressing new vessels are expected to have a very slow real-world impact and, by this same logic, measures targeting existing vessels and fuels can be expected to have a greater impact. Below, the main measures for NO_x and PM control in diesel vessels are discussed. SO_x emissions can be controlled with the provision of low sulphur fuels.

82. ***NO_x control with on-board after-treatment devices:*** SCR systems, conceptually similar to those used on road diesel vehicles, can be retrofitted on existing vessels or can be used on new vessels to effectively control NO_x emissions. However, reduction efficiency may drop in low loads (<25 per cent) and during slow steaming.

83. ***PM control with on-board after-treatment devices:*** Scrubbers are mostly known for the SO_x emission reduction they can achieve, but they can also have a positive impact on PM. They can be considered as BAT especially for new vessels (possibly combined with SCR for additional NO_x reduction); retrofit is possible, but there are technical limitations for implementation (space, weight and vessel stability constraints). DPFs cannot be considered as a mainstream technology for existing vessels. They are not ready for commercial operation and the expected effect on PM is not guaranteed to be as high as in automotive NRMM. However, DPFs may have a better future potential, especially in inland waterways where low sulphur fuel is used.

84. ***Alternative fuels:*** An option to control both NO_x and PM could be a switch to liquefied natural gas (LNG). This would additionally eliminate most of (climate-relevant) black carbon emissions and allow operators to reduce dependence on fossil fuel oil. However, this requires major modific tions and, hence, is considered economical mainly for newly built vessels. Fuel availability is currently considered the largest obstacle to its more widespread use. Attention should also be given to methane emissions from natural gas use in vessels [1].

I. Seagoing ships

85. Seagoing ships (domestic or international maritime) use the same diesel engine types as inland waterways vessels (though somewhat larger); hence, similar on-board after-treatment devices can be used for NO_x and PM control, as well as switching to LNG. Additional issues related to seagoing ships and emission control techniques specifically targeted to them are discussed below.

86. ***Emission control areas:*** Emission control areas (ECAs) are specifically designed coastal areas, where air quality problems are acute and more stringent emission requirements are mandated for ships operating in those waters. So far this has been implemented as sulphur emission control areas (SECAs) requiring much lower sulphur content in fuels, and as nitrogen emission control areas (NECAs) requiring much lower NO_x emissions from newly built (or major re-engined) ocean-going vessels. In Europe, the Baltic Sea and the North Sea are specified as SO_x emission control areas, while in the Americas, SO_x and NO_x limits are applicable for the North American, United States and Caribbean Sea coastal waters. The emission control measures, which are required in ECAs can be considered as BAT. Those include particular fuels with maximum allowed sulphur levels and/or on-board emission control technologies, e.g., SCR and scrubbers. The latter have been successfully implemented to enable heavy-fuel oil operating vessels to enter ECAs. The extension of such emission control areas can lead to additional significant air pollution benefits for the affected areas.

87. ***Fuel sulphur restrictions:*** Final targets for equivalent fuel sulphur content include a 0.5 per cent m/m solution maximum limit outside of ECA zones and a 0.1 per cent m/m maximum limit inside ECA zones for all fuels. These reductions can be achieved either with the use of low sulphur diesel fuel, or repowering of the engine with an alternative fuel (e.g., natural gas) or alternatively with the use of scrubber on board the vehicle. Economic, accessibility and technical limitations exist in either case. Any of these technical options may be a good candidate to meet reduced SO_x levels and final decisions depend on the ship type and its operations patterns.

88. ***Port-level initiatives:*** Several ports around the world have initiated programmes in which power to the ships while at berth is provided by on-shore units instead of running the ship engines. This approach may bring significant local air quality benefits for all pollutants. Universally agreed power delivery specifications is a limiting factor in extending such programmes to more ports. Country-wide emission reductions that can be achieved with such measures depend on the energy mix and the technologies used for power generation. Other port incentives include velocity control, reduction of manoeuvring, etc.

J. Aircraft

89. Low NO_x combustion and aircraft design improvements are two emission control techniques that can be implemented on each individual aircraft by the manufacturer. Low NO_x combustion is achieved with lean premixed combustion and clean combustor design — including the design of the fuel injector and the thermal liner, the dynamics and operability — while peak temperature and time spent at this temperature is limited. Aircraft design improvements concern the reduction of the basic aircraft weight, the improvement of aerodynamics and the overall specific performance of the engine, and the design of aircraft that fly at lower altitudes with reduced speed. In the latter case, attention should be given to the possible negative impacts on fuel consumption and operating cost.

K. Electric trams, metros, and trolleybuses

90. Electric trams, metros and trolleybuses do not generate tailpipe or evaporation emissions. However, they are a source of heavy metal emissions owing to the wear of their components and, in particular, friction on the rails and on the power line. Sparking that occurs in the power lines is an additional mechanism of heavy metal emissions. Emissions produced when vehicle poles glide and spark on the power lines are largely unknown and their contribution to an emission inventory is usually not accounted for. Several studies in the United States and Europe have demonstrated increased concentrations of carbon and several metals in metro stations [16] [17]. Moreover, it should not be forgotten that electric power generation is also associated with significant pollution generation problems at the power station sites, depending on the energy mix of each country.

91. Using these public transportation systems is by itself an effective measure to reduce air pollution and improve air quality in cities, by shifting traffic from private cars (and diesel buses) onto cleaner and higher-capacity electric means of transport. An indicative list of additional measures related to the usage of these transportation systems in order to increase environmental protection and energy efficie y and improve air quality is given below:

- ***Fleet and network measures:*** modernization of existing stock and fleet management optimization, increase of commercial speed through segregated tracks and traffic management measures, inspection and maintenance of rails, fixed installations, etc;
- ***General measures:*** make the usage attractive (e.g., by park-and-ride policies, low fare policies, expansion of networks, new routes), increase intermodality and reduce trip duration, use advanced traffic management systems;
- ***Technology measures:*** reduce friction through better design and materials, eliminate sparking by either mechanical or, most probably, electrical measures.

V. Implementation and non-technical measures

92. Implementation and non-technical measures are complementary to the technical ones in order to assist in further emission reductions. In particular, proper implementation measures are crucial for controlling the performance of vehicles and engines in use. Non-technical measures can support or facilitate retrofitting with BAT, accelerate introduction of new BAT (vehicles, engines) and cleaner fuels, limit traffic volumes and/or promote shifts to more environmentally friendly modes of transport such as rail, maritime, inland waterway and combined transport. In addition, with respect to urban traffic, non-technical measures also aim at better integrating land use and transport planning and developing infrastructure and facilities for low-polluting mobility (bikes, public transport, etc.). Some non-technical measures have been referenced wherever deemed necessary in the previous chapter.

93. Short descriptions of inspection and maintenance as key implementation measure and of some commonly used non-technical measures are given below. Implementations of non-technical measures may differ in practice and may be combined with specific funds and incentives schemes (structural, financial or restrictive), tolls and taxes, tax exemptions or reductions, subsidies, etc.

94. ***Enhanced inspection and maintenance schemes:*** Inspection and maintenance (I/M) is a way to check and improve the level of emissions, fuel consumption and safety of vehicles, and to repair those that do not meet specific emission standards. These tasks are accomplished with visual checks, emission measurements and the use of various technical means or devices. A basic I/M performance standard usually includes idle testing, a test of exhaust emissions and checking that critical emission control components are present and operational. An enhanced I/M performance standard includes an exhaust test and purge testing of the evaporative control system and visual inspection of the catalyst and fuel inlet restrictor. OBD is a computer-based system that continually monitors the electronic sensors, emission control system and catalytic converter to ensure they are working as designed. Remote sensing devices can also be used to measure emissions in the exhaust stream.

95. ***Environmental zones:*** The primary aim of an environmental zone (or low-emission zone) is to improve air quality by accelerating natural fleet turnover. Usually, it is a designated area where specific access restrictions are applied in order to reduce vehicle emissions and improve air quality. Regulations within the zone can include access restrictions for vehicles that do not comply with set emission standards and/or access restrictions based on the vehicle registration plate limiting access on certain days or peak hours. Non-compliant vehicles entering the zone are usually charged with penalty fines.

96. ***Accelerated scrappage schemes:*** Older and high-emitting vehicles meeting less stringent emission standards and with degraded pollution control equipment often emit a disproportionately high share of total emissions. Accelerated scrappage schemes are early retirement programmes for older vehicles, usually established by giving grants to vehicle owners. These schemes are quite likely to achieve environmental benefits, since newer vehicles meet more stringent emission standards and allow for greater fuel savings. Replacing an entire vehicle may be the best option for a vehicle that is near the end of its useful life or was manufactured before stringent emissions standards were put in place.

97. ***Modal shift to public transport:*** Incentives and policies to promote a modal shift to cleaner public transportation systems is an effective measure to reduce air pollution and improve air quality in cities (e.g., shifting traffic from private cars and diesel buses to higher capacity electric means of transport such as trams, metros, and trolleybuses, or buses that use cleaner fuels, powertrains, etc.).

References

1. Giannis Papadimitriou and others, "Best Available Techniques for Mobile Sources in support of a Guidance Document to the Gothenburg Protocol of the LRTAP Convention", Final Technical Report for European Commission Directorate General for Environment (13 March 2015). Available from http://emisia.com/sites/default/files/B T_Final.pdf. This report was also submitted as an information document to the Working Group on Strategies and Review at its fi ty-third session and is available on the web page for that meeting (http://www.unece.org/index.php?id=35605#/).
2. Leonidas Ntziachristos and Maria Cristina Galassi, "Emission factors for new and upcoming technologies in road transport", JRC Scientific and Policy Reports, Report EUR 26952 EN (Ispra, Italy, Institute for Energy and Transport, July 2014).
3. IHS Global Insight, Assessment of the Effectiveness of Scrapping Schemes for Vehicles: Economic, Environmental, and Safety Impacts, Final Report for the European Commission Directorate General for Enterprise and Industry, Automotive Industry (March 2010).
4. Organization for Economic Cooperation and Development and United Nations Environment Programme, Older Gasoline Vehicles in Developing Countries and Economies in Transition: Their Importance and the Policy Options for Addressing Them (Paris, Organization for Economic Cooperation and Development, 1999).
5. Anwar Gary Haq, Giorgio Martini, and Giorgos Mellios, "Estimating the Costs and Benefits of Introducing a New European Evaporative Emissions Test Procedure: final report", JRC Scientific and Policy Reports, Report EUR 26057 EN (Ispra, Italy, Institute for Energy and Transport, 2013).
6. International Council on Clean Transportation, European Vehicle Market Statistics: Pocketbook 2014 (Berlin, November 2014).
7. David C. Carslaw and others, "Recent evidence concerning higher NO_x emissions from passenger cars and light duty vehicles", Atmospheric Environment, vol. 45, no. 39 (December 2011).
8. Vicente Franco and others, "Real world exhaust emissions from modern diesel cars: a meta-analysis of PEMS emissions data from EU (Euro 6) and US (tier 2 bin 5/ulev ii) diesel passenger cars" (Berlin, International Council on Clean Transportation, 2014). Available from http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars.
9. L. Eudy, K. Chandler, and C. Gikakis, "Fuel Cell Buses in U.S. Transit Fleets: Summary of Experiences and Current Status", Technical Report NREL/TP-560–41967 (Golden, Colorado, United States of America, National Renewable Energy Laboratory, September 2007). Available from http://www.nrel.gov/hydrogen/pdfs/41967.pdf.
10. European Environment Agency, EMEP/EEA air pollutant emission inventory guidebook 2013, EEA Technical report No. 12/2013, technical chapter 1.A.3.b.vi-vii Road vehicle tyre and break wear, road surface wear (Luxembourg, Publications Office of the European Union, 2013).
11. Hugo A. C. Denier van der Gon and others, "The Policy Relevance of Wear Emissions from Road Transport, Now and in the Future — An International Workshop Report and Consensus Statement", Journal of the Air & Waste Management Association, vol. 63, No. 2 (November 2013).
12. Janne Berger and Bruce Denby, "A generalized model for traffic induced road dust emissions. Model description and evaluation", Atmospheric Environment, vol. 45, no. 22 (July 2011).
13. European Union, European Commission Joint Research Centre, "2007 Technical Review of the NRMM Directive 1997/68/EC as amended by Directives 2002/88/EC and2004/26/EC" (Ispra, Italy, Institute for Environment and Sustainability, September 2008).
14. European Environment Agency, EMEP/EEA air pollutant emission inventory guidebook 2013, EEA Technical report No 12/2013, technical chapter 1.A.4 Non-road mobile sources and machinery.

15. European Commission, "Proposal for a Regulation of the European Parliament and of the Council on requirements relating to emission limits and type-approval for internal combustion engines for non-road mobile machinery", COM(2014) 581 final (Brussels, 25 September 2014). Available from http://ec.europa.eu/transparency/regdoc/rep/1/2014/EN/1–2014–581-EN-F1-1.Pdf.

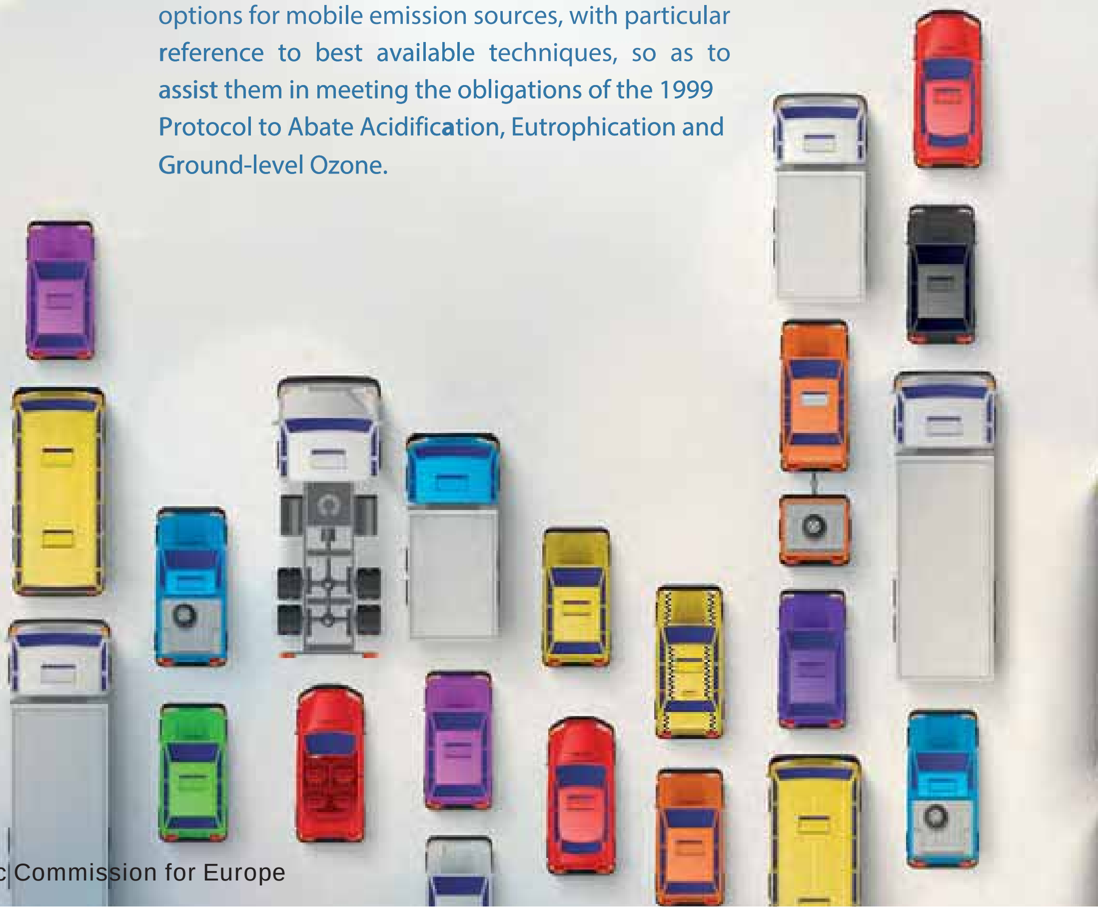
16. Winnie Kam and others, "A comparative assessment of PM2.5 exposures in light-rail, subway, freeway, and surface streets environments in Los Angeles and estimated lung cancer risk", Environmental Science: Processes and Impacts, vol. 15, No. 1 (January 2013).

17. Winnie Kam and others, "Chemical Characterization of Coarse and Fine Particulate Matter (PM) in Underground and Ground-Level Rail Systems of Los Angeles Metro", Environmental Science and Technology, vol. 45, No. 15 (August 2011).

Guidance Document on Emission Control Techniques for Mobile Sources under the Convention on Long-range Transboundary Air Pollution

At its thirty-fifth session (Geneva, 2–4 May 2016), the Executive Body adopted the Guidance Document on Emission Control Techniques for Mobile Sources, as contained in the present document. It replaces the 1999 guidance document on control techniques for selected mobiles sources.

The document aims to provide Parties with guidance in identifying the best abatement options for mobile emission sources, with particular reference to best available techniques, so as to assist them in meeting the obligations of the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone.



Information Service
United Nations Economic Commission for Europe

Palais des Nations
CH-1211 Geneva 10, Switzerland
Telephone: +41 (0) 22 917 44 44
Fax: +41 (0) 22 917 05 05
E-mail: info.ece@unece.org
Website: www.unece.org

ISBN 978-92-1-117114-3

Designed and Printed at United Nations, Geneva – 1618807 **(E)** – November 2016 – 927 – **ECE/EB.AIR/138**