

## Wissenschaftliche Arbeiten

# Support for reducing particulate and NOx emissions from existing vehicles

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Mit 1 Abbildung und 1 Tabelle

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The European Commission has commissioned this research project to identify cost effective technical measures to reduce PM and NOx emissions from existing heavy duty vehicles and produce concrete policy proposals for the European Commission to support their use. The project has also produced data and scenarios to enable the Commission to undertake cost effectiveness modelling of the most promising technical measures, to assess their potential impact and costs.

The work has been undertaken by a consortium led by Sadler Consultants together with Sustainable Transport Solutions (STS) and the Institut für Energie- und Umweltforschung Heidelberg GmbH (IFEU). The research is now with the Commission at draft report stage following stakeholder input from around the EU and US and a workshop in Brussels.

Technical measures are defined in this project as technical interventions that lead to lower particulate (PM) and nitrogen oxide (NOx) emissions per vehicle km under comparable operating conditions, and those identified for detailed assessment included retrofits and cleaner fuels.

This project has three main parts:

1. A technical review of potential technical measures
2. Development of policies at an EU level to support the promising technical measures
3. Presenting scenarios and data for TREMOVE modelling for the most promising technical measures, in the light of the policies developed.

Questionnaires were circulated to gain stakeholder and expert views on both data on technical measures and policies relating to technical measures and transport emissions reduction. These responses were combined with other information sent, literature reviews and team expertise.

### Technical Review

A wealth of information was gathered and compiled into a detailed analysis of the different options available. and the technical measures were reviewed with the objective of

identifying the most promising options for the Commission to support. The technical measures within the paper were categorised as set out below, as well as the most preferable options identified:

#### Primary measures

- measures which have quantifiable benefits and are considered the most promising technical measures for reducing PM and NOx appropriate for the policies within this project.

#### Secondary measures

- measures which, whilst not providing significant impact upon PM and NOx, should be encouraged to be used in conjunction with primary measures.
- measures which appear to offer potential NOx and PM benefits but which should be further examined to explore their potential in a European context.

#### Other measures

*[Categorisation as 'other measures' is within the context of this project, and does not mean that they are not valid technologies, particularly in many cases in terms of CO<sub>2</sub> emissions.]*

- immature or technologies not close enough to market
- measures not able to impact significantly upon the emissions from existing heavy-duty vehicles
- measures which appear to be too expensive versus other technologies offering similar or better emission benefits

The measures that have been assessed to lie within each of these categories are set out below:

#### Primary measures

##### Exhaust emissions retrofit measures

- Diesel Oxidation Catalyst (DOC)
- Diesel Particulate Filter (DPF)
- Exhaust Gas Recirculation (EGR)
- Selective Catalytic Reduction (SCR)
- SCR+DPF
- Re-engining / repowering

##### Alternative liquid fuels

- Diesel Water Emulsion (DWE)

##### Alternative gaseous fuels

- Dual-fuel Natural Gas
- Dual-fuel Bio-methane

#### Secondary measures

- Low Ash Lubricants
- Closed Crankcase Ventilation systems
- Measures to reduce impact of idle emissions – use of APUs (auxiliary power units, truck stop electrification)

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### Other measures

#### Exhaust emissions retrofit measures

- Lean NOx Traps (LNT) – due to the early stages of development, difficulties with sulphur poisoning and very low sulphur fuel and lubricating oil requirements

#### Alternative liquid fuels

- Dimethyl-ether (DME) – due to the early stages of production and volume uncertainties
- Fatty Acid Methyl Esters (FAME) – due to the low impact on PM and NOx emissions
- Synthetic Diesel (Fischer-Tropsch) – due to early stages of production and volume availability, and therefore uncertainties
- Ethanol – as not currently practical as retrofit measure, although this could be a market forces, rather than technical. issue

### Other measures

- Dedicated Gas conversions - expensive for little advantage over diesel with DPF+SCR
- Fuel Additives (other than FBC) - due to the low impact on PM and NOx emissions
- Retrofit hybrid drives - due to their early stage of development, and therefore supply uncertainties
- Low Viscosity Lubricants - due to the low impact on PM and NOx emissions
- Low Rolling Resistance Tyres - due to the uncertainty of the impact on PM and NOx emissions

The review of the technical measures found that the most promising were diesel particulate filters (DPF) for reducing particulate emissions and selective catalytic reduction (SCR) for reducing NOx. The most promising fuels were diesel water emulsion and dual-fuel natural/bio gas, although they were less promising in terms of cost effective emissions reduction than the existing diesel vehicles fitted with DPF and SCRs.

Full flow Diesel Particulate Filters (DPFs) were considered to be the most important technology for particulate emissions reduction and should be prioritised. They can reduce PM by greater than 90% for particulate mass and in excess of 99% for particles in the size range 10 – 1000nm. Catalysed DPFs need duty cycles that enable regeneration and can increase NO<sub>2</sub>. Active regeneration or fuel borne catalyst systems offer no increase in NO<sub>2</sub>.

Selective Catalytic Reduction (SCR) uses ammonia (either as urea with 32.5% ammonia or as 16% liquid ammonia) as a reductant, and can reduce NOx emissions by up to 85%. SCR systems require a minimum of 200°C exhaust temperature to be effective, so system, engine and duty cycle need to be matched. Therefore SCR, preferably in conjunction with DPF, should be prioritised as a retrofit option for NOx and PM control.

In the context of this project, only diesel water emulsion (DWE) is considered a practical alternative liquid fuel or fuel additive at this stage, although it is a niche fuel for captive fleets due to the fuel storage issues. This can reduce emissions of NOx by 15% and PM by 50-60%, although results are extremely variable. The use of „dual fuel“ engines using a mix of methane gas (65-85%) and diesel is an option that can achieve Euro 4 emissions. Availability of the refuelling infrastructure, and for bus fleets and refuse vehicles space for on-vehicle storage tanks

remain issues. Whilst dual fuel systems can be a commercially viable option, depending on operational requirements, diesel engines fitted with SCR+DPF systems are likely to be more cost effective specifically for the reduction of NOx and PM.

The technical measures were ranked using a non-weighted ranking that included PM, NOx, NO<sub>2</sub>, solid particles under 1000nm and cost, but not including CO, HC and other pollutants. The outcome of the ranking is presented below, and concurs with the technical review conclusions. This ranking was used to decide which technical measures to include in the model scenarios.

### Technical measure ranking

Measure	Overall ranking
SCR+DPF (active regeneration)	86
DPF (active regeneration)	86
DPF (FBC)	86
SCR+DPF(CRT®, catalysed)	81
DPF (CRT®, catalysed)	81
DOC	79
DWE	72
SCR	71
Dual fuel diesel/natural gas/biogas	69
DPF (partial flow)	67
Repower to Euro 4	65
Ethanol	64
EGR	60

The Commission will be able to model the impact and costs of these technical measures with TREMOVE using the data and scenarios provided within the report.

### Policy Support Overview

In terms of support for these technical measures, there is a clear and urgent need for the Commission to take action to help support the use of retrofits through a common EU-wide certification scheme. Such a scheme is described in this report. It would enable Low Emission Zones (LEZs) to use retrofits without risking falling foul of the EU freedom of movement issue. It would also allow LEZ emissions standards to require for example Euro X plus 90% emissions reduction – giving clear incentives for retrofits and cost effective emissions reductions. The EU-wide certification scheme will, depending on state aid reviews, also enable financial incentives to be streamlined through the notification process, as well as give reassurance for those member states not yet using retrofits that they are robust technology and could act as Best Available Technology (BAT) references for retrofits.

Other measures to support LEZs and financial incentives have also been identified, including LEZ guidance, labelling of Euro standards, informal/semi-formal groupings of LEZ cities, information sharing on LEZs, certification schemes and financial incentives, and resolving state aid issues. There are also a number of fiscal measures that would support increased use of technical measures, including guidance and modifications to the state aid procedure, allowing no VAT on technical measures and investigation into whether procurement consortia could assist.

The measures should be as all-inclusive as possible, in line with the interoperability principle. Measures should be for all vehicles, including light duty vehicles, and not aimed just at heavy duty and captive vehicles, and as far as possible be technology

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neutral, however this report focuses on heavy duty vehicles due to the project remit.

Within EU-wide certification, there is a priority on some mechanism to enable PM retrofits certification for the currently proposed LEZs over the next two years. The policies that are recommended to be implemented are outlined below in order of priority:

Recommended concrete proposals (by priority):

1. Mechanism for retrofit certification for currently planned LEZs including web information on LEZ and certification schemes
2. Labelling of Euro standards for LEZs (out of remit for this project)
3. Enforcement against foreign vehicles (out of remit for this project)
4. EU-wide certification
5. LEZ guidance (some high level LEZ guidance is planned in the EU Urban Transport Green Paper, but further guidance is needed)
6. Informal/semi-formal grouping of LEZ cities
7. Information sharing (2)
  - Web information on existing financial incentives
  - Maps and GPS information on existing LEZs
8. State aid issues detailed in the report -although the timescale for this is determined by the current review of the environmental state aid guidelines and the state aid action plan

There are some differences between priority and best/possible timescales. The grouping of LEZ cities and the second set of information sharing could be done relatively easily quickly to the benefit of cities and LEZs particularly in the shorter term. The current reviews of the state aid environmental guidelines, de-minimis ruling and the state aid action plan set an imminent timescale for resolving the state aid issues.

### EU-wide certification scheme

The EU-wide certification scheme is needed as soon as possible, and the technical side could be completed in around 6-9 months, and consensus should be relatively easy to reach. However, the choice of legal mechanism/framework is likely to be the key timescale factor, and if the scheme needs to be through a legal mechanism, then timescales are likely to be longer.

Retrofits have the potential to be encouraged through LEZs and road charging, either requiring retrofits to be fitted or operators choosing to use retrofits to comply with set emissions standards. Commission action could give significant assistance to this. The main reason for this is that the freedom of movement aspect of the Treaty of Rome requires that member states do not operate barriers for vehicles from other member states. This means that LEZs have to be equally easily accessible for both foreign vehicles and national vehicles. This has two key impacts:

- a. Emissions standards need to be set to Euro standards, which are equally accepted across the EU. However, particulate traps can reduce emissions of PM by 90%.
- b. National proofs for retrofits are not allowed to be the sole requirement for LEZs, and LEZ operators need to know emissions standards/ retrofit status of foreign vehicles, in the context of many vehicle registration agencies not having and/or sharing the relevant information.

Both of these would be eased by an EU-wide certification scheme, as retrofits would be clearly identified across Europe and it would enable emissions standards to be set as Euro standard plus X% emissions reduction. It would also help cities implement tighter LEZ emissions standards than would be possible otherwise including NOx emissions reductions – for example, for London to implement a Euro 4 (PM and NOx) standard in 2010, instead of the currently envisaged Euro 4 (PM). [Reference: London LEZ Strategic Review Report, TfL]

The scheme should allow for treatment of each pollutant separately, and set up to be able to be used for all pollutants that are, or may be in the future, a problem. The scheme should be designed initially for PM and NOx, and be designed to allow extension to other pollutants as the need may arise, including CO2. It would primarily be for retrofits, and could also be for conversion to alternative fuels, and non-petrol/ diesel fuels/ additives if desired, probably at a later stage. It should be clear, straightforward and user friendly to transport operators who will be purchasing the retrofit devices.

There would be two parts to the certification. Firstly approving the device. Secondly certifying that the vehicle has a certified device fitted. The first part would be operated by a certifying body to the standards set out in the scheme, which would also set out what technical measure could be fitted to which vehicle. The second part would be operated by the technical measure provider who would then inform the certifying body that a measure has been fitted, which is then spot-checked by the certifying body.

There is a clear requirement for any EU-wide certification scheme to offer both Euro standard equivalence and percentage reduction from baseline emissions performance under real-world operating conditions. This is required to provide comparison with Euro standards which most of the LEZs will base compliance upon, and, importantly to ensure that technical measures perform correctly under real-world operating conditions. An EU-wide certification scheme must therefore be based on an engine dynamometer (bench) test [In the context of this project it is specifically as per the homologation test where the engine is tested on the engine dynamometer without being installed in a vehicle. The test is designed to enable the assessment of power, torque, fuel consumption, emissions under controlled conditions.] utilising current engine homologation test [Engine dynamometer test conducted under controlled laboratory conditions to determine if the engine meets the regulatory requirements for emissions compliance] cycles (ESC, ELR, ETC [ECS: European steady-state cycle, ELR: European load response (for smoke), ETC: European Transient Cycle]) for validating the performance of the technical measure under controlled laboratory conditions; coupled with a period of in-service operation over a representative duty (chassis dynamometer [Where the whole vehicle is put on a rolling road and tested through a simulated drive (test) cycle. There tend to be a wider range of chassis dynamometer tests used than engine tests.], drive cycle or on-road [Where a vehicle is tested on a normal road or road track with emissions monitoring equipment in the vehicle itself]) cycle to prove that the retrofit works for specific applications, is durable and includes issues such as regeneration of the particulate trap. Overall certification would be for different operations, such as lorry, urban bus, coach, refuse vehicle using different drive cycle tests for each operation, together with one engine homologation test required per technical measure per engine family.

Engine dynamometer based tests is needed for baseline certification on an engine family basis using Euro standard test

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cycles – ESC, ELR, ETC. To test each engine power rating within a family would be prohibitive in cost, therefore a worse case approach i.e. most arduous operating conditions should be taken to ensure that the device operates in all conditions and loads. Whilst a diesel particulate filter will provide high filtration efficiency at all speeds and loads (as long as it regenerates), an SCR system might operate efficiently at high load and speed (due to the high exhaust temperature) but not at low load and speed (due to the low exhaust temperature). The certifying scheme should give guidelines on the scope and extent of engine test speed/load sites applicable to the technical measure being assessed, together with data and reporting requirements. Guidance could be given on the expected pollutant emission reduction rates under specific test conditions, although it would require a lot of correlation work to be able to confidently provide such guidance, and reviewing the final data is likely to be more appropriate. The scheme will allow comparison with Euro standards. However it will result in pre-Euro 4 diesel engines being baseline tested over test cycles they were not originally homologated to in order to determine percentage benefits conferred by retrofit technologies that can be compared with Euro 4 and later engines.

Durability and operational aspects will be covered by in-service and chassis dynamometer drive cycle demonstration, but including additional chassis dynamometer testing after the durability test. The specification and provision of the specific drive cycle would be the responsibility of the technical measure supplier, carried out to scheme requirements, and would be approved by the certifying body before testing. This test would provide the application/ operation-specific aspect of the certification. This may use approved drive cycles or may be bespoke to the application. The durability and in-service demonstration phase would be followed by further engine dynamometer tests to confirm performance after 2000 hours operation.

### Potential management structure of the scheme:

A possible management structure to the scheme could be as outlined below. Groups 2-7 are those envisaged for the certification scheme, groups 1 and 8 are optional for other technical

measure or implementation mechanisms. This structure may be appropriate as part of the legal/ framework arrangements of the scheme, or the management structure which sits under them.

### Emissions requirements

The scheme should be output-driven and technology neutral, and not require fitting of particular technical measure. The test certificate should set out the test results required in an 'impacts table'. This will allow the LEZ/road tolling/incentive scheme to choose the technical measures that are valid for its scheme. It would allow existing requirements to be serviced, as well as allowing the option in the future of percentage emissions reduction requirements – for example 90% reduction in PM, which would allow significant emissions reduction through retrofits.

The 'impacts table' should include the percentage emissions reduction, g/kWh or g/km, and what Euro standard original vehicle the technical measure takes to which Euro standard for each pollutant. It would also label Euro standard for each pollutant, taken from the engine dynamometer test. This would allow both comparisons with current Euro standards and greater flexibility about the emissions standards set.

It is recommended that the PMP protocol should be introduced as the main measure of PM emissions reduction when possible, in addition to the PM<sub>10</sub> metric. This protocol allows for much lower detection levels and greater degrees of repeatability than the current gravimetric method. It also allows for the determination of particle number, and a clearer link with the particles of most concern to human health. The 'impacts table' would also include the impacts on other pollutants that would be specified in the testing regime.

The scheme should also require in-service compliance testing. For PM retrofits it should be with either a free acceleration smoke test combined with on-board diagnostics (simple OBD (on board diagnostics)) to monitor exhaust back pressure – combined with a visual inspection. For NOx retrofits it should be with a simple OBD either measuring NOx, or for SCR an alternative could be measuring urea, fuel and kilometres travelled. None of the OBD would attempt to interact with the engine

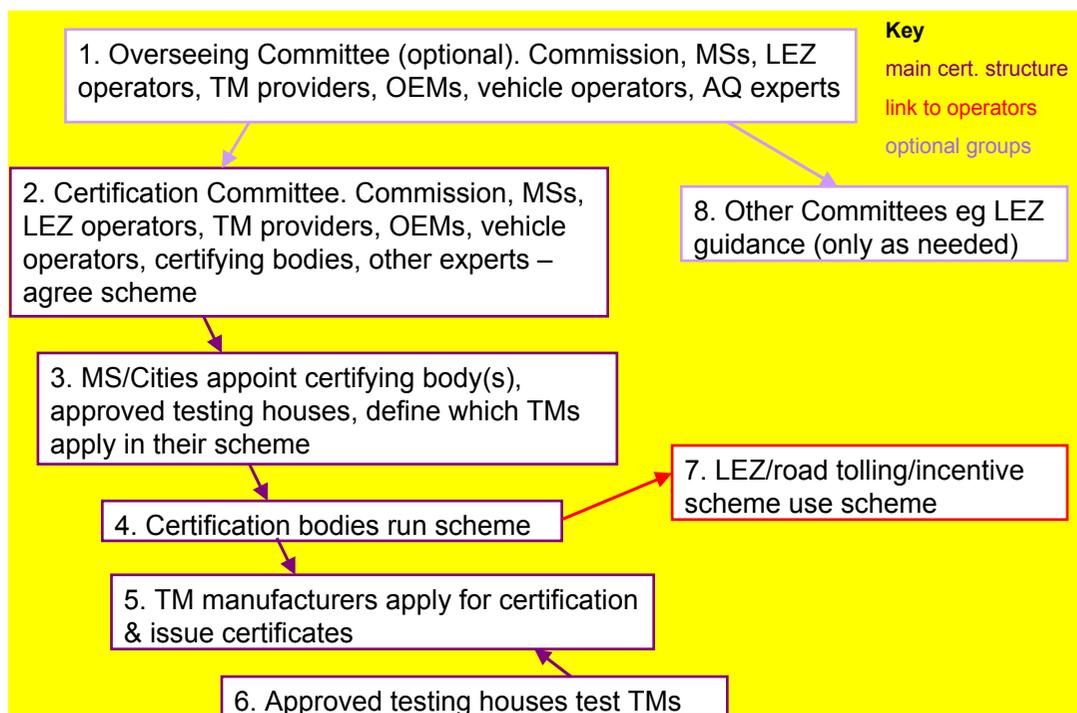


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power ratings, but would instead have a datalogger and a warning light. Gas conversions would use the current petrol idle emissions test, although with dual fuel diesel/gas engines this may need further development.

Other issues covered in the scheme outline include:

- Data and enforcement
- Number of tests required
- Compatibility with other Technical Measures
- Durability requirements
- Warranty
- Operation and Maintenance requirements
- Vehicle Registration Document alterations following retrofit
- Legal status of retrofitted vehicles

The report is now being considered by the Commission, and comments are welcome. Additional material can be found on [www.airqualitypolicy.co.uk](http://www.airqualitypolicy.co.uk), or from [Lucy.Sadler@airqualitypolicy.co.uk](mailto:Lucy.Sadler@airqualitypolicy.co.uk)

### Disclaimer

The work described in this article is based on the work of the project team, with input from colleagues around Europe and the US, and in the case of the technical measures data, peer review and information from an operator survey. It DOES NOT include views from the EU Commission, and inclusion of proposed policies in this document should not indicate that they have support from the Commission, or are necessarily implementable by the Commission.

### Die Autoren

Lucy Sadler is an independent consultant, operating through Sadler Consultants, and is currently leading a research project for the European Commission on support for technical measures detailed here. Lucy was previously the head of air quality at the Greater London Authority for the Mayor of London, and prior background includes emissions inventories, a Masters Degree by Research, prototype vehicle emissions monitor trials, research and development for gas analysers and a physics degree.

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