Appendicies to the "How can the EU support the use of technical measures in existing heavy duty vehicles" pre-workshop discussion paper

Appendix 1 Issues raised that are outside the remit of this work

Some issues raised are outside the remit of this work, or have been already tried and ruled out, or excluded from further examination by the technical review. These include:

1. Overall Clean Vehicle Standard
2. Requests for the EU to require MS to undertake measures – unlikely to be feasible, incorporated elsewhere
3. Low rolling resistance tyres, biofuels such as RME, dedicated Natural Gas – technical review indicated not effective for air quality
4. Issues affecting off-road vehicles and light duty vehicles
5. A lower rolling resistance tyre scheme for passenger cars
6. Inspection and maintenance
7. Wider issues about cleaner and more sustainable public transport
8. Limited availability of hybrid vehicles and other low carbon vehicles
9. Telematics
10. Calls for greater funding for technical measures
11. Euro standard issues
12. Allowing larger lorries
13. Intrinsic barriers such as the emission trade-off between NOx and PM
14. Speeding up introduction of lower sulphur non-road diesel fuel
15. Adapt the Common Agriculture policy to promote the production of biofuels
16. Lift off tolls from imported biofuels
17. Making the Biofuels Directive compulsory
18. Lack of (global) sustainability audit on biofuel raw materials
19. Limits on the use of studded road tyres and winter tyres – the solution is normal tyres, and local measures are tackling these issues where they are appropriate.
20. It could also allow member states to set environmental standards for imported used vehicles.
21. Interpretations of the EU air quality Directives.

Appendix 2 Table of certification schemes

	To prove	In-use compliance	Durability	Require:	Other Emis	Back Pressure	Additive	Monitoring	Safety	Noise	Other
VERT	EU homolog. off-road bench test 4 points of 8178 100 / 60% engine speed; and 100 – 50% engine load. Deviations only at 1 test point, and <1 standard deviation. Filtration is independent from engine raw emission. One family of DPFs is tested on a standard engine and is applicable for all diesel engines sized accordingly.	Free accel <0.24 m-1 by manufacturers annually on every deployed device. Failure rate >5% results in delisting	Free accel >0.12m-1 after 2000hrs op. >2000hrs before cleaning. Maintenance interval >500hrs. Materials guarantee 2yrs/1000hrs. Life expectancy >5000 op hrs	PM count. 20-300nm >95%, PM mass >90%, particle size distribution, particle composition, worst case conditions (filtration during regen. with full & empty filters), dynamic effects, &more	No increase in secondary emissions. CO, HC, NOx & PM, incl. during regen. as usual % of cycle average. No incr NO_2, dioxins, furans, PAH, Nitro-PAH, sulphuric acid aerosols, secondary PM, mineral fibre	Fresh filter <50mbar. During regen. <150 mbar Max <200 mbar 95% percentile Alarm at >5 sec above 200 mbar	Automatic interrupt if filter ruptures	Monitor filter performance, backpressure, & additive	Cause no additional risks. Mounted as per instruction Meet Swiss safety standards.		Label must be durable etc w filter family, serial no, manufacturer data. The only cert. scheme to look at particle number, ultrafines and particle composition. Cannot confirm that regen will happen for each engine application.
German & Dutch HDV. Not yet finalised	Engine bench certification according to 88/77/EC. ESC & ETC cycles. Maybe also modified ESC (tbc). Engine family approach like the US - 100-6% of base engine within the scope of application (engine family with respect to annex I item 8.2 of directive 88/77) & smallest used filter volume within the scope of application. Emissions tests every 5th ETC cycle to test regen.		efficiency guaranteed when operating according to its intended to 200000 km. Engines with swept volume <0.75 dm^3/cylinder & speed >3000 min^{-1} require 80 000 km. Endurance test of >25 ETC cycles – also to test regen. Free maintenance included in sale contract as often as required up to 80000 /200000 km	gravimetric PM reduction. Class A 90% reduction. Class B 50%. Systems for engines with a swept volume <0.75 dm^3/ cylinder & speed of >3000 min^{-1} a minimum of 30% is applicable.	As per originally approved Euro class. NO_2/NOx ration recorded in initial and retrofitted state. Opacity according to 88/77 <0.8m^{-1}. Maximum 4% fuel penalty	Regen. test under boundary loaded conditions - boundary loading or after maximum 100 hours a thermal regeneration is initiated – <15% deviation from pre-loading test data for gases & <20% for PM. Must state that exhaust gas temps in regen. are non-critical	No additive allowed with Class B. If additive used, issue statement of no objection of the combination of additive & system from Government Agency	Temporarily disabling of the system if not meet requirements. Prove: a) conditions disabling activated / deactivated b) disabling only to protect engine or DPF & not permanent. c) lasts max 2 test cycles d) durability criteria still met e) driver informed. Existing OBD /engine management not impaired.	Normally >2m between system & turbocharger	No deterioration	Requirement phrasing different in DE and NL due to legal structure, but in practice identical. Dutch scheme presented here as per mid August. Conformity of production requirements. Specifies fuel. Installation manual requirements specified. Each system sold have installation manual & copy type approval. Can withdraw approval
German &	EU homologation cycle,	Opacity	>4,000 km on	Gravimetric.	arithmetic	Must be					Worst case regen

Dutch LDV	NEDC. Under all instances average PM deviate <15%	test during free accel with respect of article 2.3.12 of the Regulation on permanent requirements	dyno with urban & extra-urban on Euro3 N1, N1 class II or III, Euro2. <70kph, 300°C, or realistic urban cycle. Shorter test if reduced PM by same %. Efficiency guaranteed if used according to intended use for 5yrs / 80000km. Range of use for engine capacity 65 -130%, with respect of engine capacity.	PM reduced < 0.025 g/km; vehicles > 2.5T & N1 class II & III, 0.050g/km. Retention coefficient 30-90%, during soot oxidation 30%.	mean of NEDC in initial state without a reduction system for HC, CO, NOx, CO_2, worst case regen. disregarded	designed & built so that no unacceptable increase in exhaust gas back pressure occurs during load when no regen. takes place or after extended use,					tested as proof of thermal stability. Conformity criteria required. Customer has copy of type approval certificate. Installation manual required
RPC (UK)	To certify a DPF: test on 'worst case' examples of engine families for different vehicle types. Witnessed test on ETC. Previously used dyno on FiGE as 'real-world' proxy for ETC.	Free accel. smoke test & visual test matching serial no of DPF with chassis & vehicle registration		Euro 4 (PM) 0.03g/kWh on ETC. Previously was provisional E4(PM), 0.08 g/kWh equiv. on dyno 0.08g/km							
Danish	stationary 13-mode on Euro1. Measured emissions must be representative of emissions in practical use. Manufacturer sends declaration, safety DTI assess design & guide	Free accel K-value < $0.2m^{-1}$. Must be possible to insert opacity test.	Designed to be operational in full lifetime of vehicle if engine & filter maintained with service guidelines	80% PM reduction (E3→E4)	Present CO, HC, NOx, NO_2 data	Back-pressure <20kPa at max power	If required must be added during normal operation. Bunked vehicles are exempt	Filter status continuously warning lamp for driver if back-pressure >limit	No fire risk. assess design & guide	> same	provide service & disposal guide. Use maximum 50ppm S fuel.
WVTA - CNG cars	EU homologation tests basis. Type approval procedure and self-certification procedures.	Simplified procedures for small numbers									Whole Vehicle Type Approval.

Italian	With reference to Directive 88/77/EEC & another decree, group of engines tested. Tested with & without device. For discontinuous regen. systems test a) new system and b) under conditions similar to critical conditions (before regen.)	At users request civil motoring authorities check conformity. Installation instruction must be followed.	>50000 km drive cycle or dyno bench collection program for >1000 hours. Specify operating conditions & test before durability. PM increase <20% by end.	PM reduction. Euro1 : 0.36g/kWh, if power = 85kW coefficient of 1.7. Euro 2: 0.15 g/kWh Euro 3: 0.10 Euro 4: 0.02 Euro 5: 0.02	CO, HC, NO_x, PT tolerance band of <20% cf. those in standard the engine is type approved to. No increase in CO & HC. NOx increase by <5%	Back-pressure alarm when excessive	Must not damage vehicle or device, provide safety datasheet, consequen ce of lack / excess, set correct use, meet EN590				Not technical solutions that facilitate exclusion or chocking of system by bypass devices. Label device. Conformity of production. Recognise other EU/EEA/Turkey schemes. Amends vehicle registration documents
EST Clean-Up	Chassis dynamometer based. Cycles include Millbrook London Transport Bus (MLTB), FIGE institute, and Refuse Collection Vehicle (RCV) cycles	Not a certification scheme as such, but included out of completen ess as it uses drive cycles	6 month in-service use followed by repeat emissions tests	All PM and NOx reduction technologies.	Ultrafine measurements with Electrostatic Low Pressure Impactor (ELPI). NOx speciation for CRT and catalysed traps						
Sweden	Chassis dynamometer, using the Braunschweig transient test cycle by AVL-MTC										
France	UTAC. Dynamometer testing, with a certification system										
Others	There have been other dynamometer testing in Holland, Belgium, Denmark, Sweden, and Finland, either certifications, or testing to support public procurement, often of buses										
Tokyo	Board of experts conducting the inspections and the designations, with data			Certification of DPFs and DOCs							
Korea	Various tests such as actual test, emission reduction efficiency test, performance test		Warranty : Type 1 3y/ 160000km, Type 2&3 3y/80000 km,	Type 1 PM, NOx reduction >70% (DPF). Type 2 >50%, Type 3 > 25% (DOC)							
CARB	Cycle (% reduction) or bench (absolute level & %). Incl. during regen, include aborted/ uncompleted tests & state why not completed. Field	No annual test. >=4 devices tested after 50 units sold. Each <=90%	Min stability demonstration 80500km/1000 hrs. Field / lab-based demo with chassis / dyno. Warrantee	3 levels. Level 1 25% PM reduction Level 2 : 50% PM reduction Level 3 >=85% PM reduction	NO_2 <20 % increase, NOx on mass basis report total PM, CO_2 can ask for extra tests. NH_3	In emission & durability test, backpressure within OEMs specified limits, or will not result in any	Must be safe to use alone. Monitor shut off additive if problem.			Same as befor e	State maintenance requirements. Label system. Controls relying on fuel changes ie additives / alternative diesel fuels must evaluate

	demonstration an option. Filter break-in 25-125 hours.	lower bound of initial verification level. Total no tested <=10.	>=5yr/241400 km, or if typically driven over 161000km /yr & has < 483000km when installed 2yrs unlimited mileage	or PM <=0.01 g/bhp-hr. Level 3 tested during regen.	<25ppm. CO < current limits for new diesel, NMVOC , NO_x incr <10% or prove widespread use will not incr O_3.	engine damage. If gets gradual buildup, state how to reduce. Incl. backpressure monitor to inform operator	Submit env, toxicologic al, epidem. data every 2yrs. Run with >50 ppm or x10 usual rate				multimedia effects. Owners manual required & content specified, incl. maintenance. Specifies fuel. Not test extreme DPF conditions i.e. highest space velocity.
CARB NOx	2 hot-start tests + cycle that gives sig. periods of elevated NOx. Cycle must be representative.	Rest as above									
USEPA	Dyno cycle on under load, 40 CFR Part 86 Subpart N after device run-in. Min 3 hot start and 1 cold tests with 95% confidence interval. Additional tests required if confidence interval too large. If include periodic regen., sufficient test cycles until include regen event. Multi-family applications, test with one engine, use sizing charts for relevance on different engines if verified on an engine at most challenging end of applicability. Also requires field tests. Reports to USEPA from approved lab.	No annual test. After 500 units sold testing at 25% and 75% of mileage or hours meet 75% of verified level.	Real world operation to 33% of full-life (5yrs or 100khrs), and accelerated bench testing 33% of full-life. operating new device under conditions that cause normal wear equiv. >= 33% of min required by CARB	No particular requirement, states what emissions reduction device gives	NOx, PM, HCs, CO, CO_2 & other FTP specified emissions.	Not exceed backpressure. DPF inlet/outlet temp and pressure during tests must be reported.			Maint ain physi cal integri ty		Same appearance and location as large muffler. State if OEM warrantee given or not. Quality assessment. Maintenance procedure submitted. Specifies fuel. SCR, NOx control technologies, fuels, fuel additives, reformulated fuels, and lubricants specifically excluded.

CARB alternative diesel fuel test for fuels to reduce PM and NOx, e.g. water-diesel emulsified, biodiesel, ethanol-diesel-emulsified and Fischer Tropsch fuels. The interim procedure specifically does not verify the appropriate use of alternative diesel fuels or possible impacts on engine durability and performance.

The procedure compares the NOx and PM emissions from a 10 percent aromatic California diesel reference fuel to the emissions from the alternative diesel fuel. It specifies the required emissions tests and analytical methods to conduct the assessment. In addition to NOx and PM

emissions, it requires an assessment of toxics and hydrocarbon emissions - no increase in toxicity shall result from an alternative diesel fuel. Hydrocarbon emissions shall be at least 25 percent lower than any applicable diesel vehicle emission standard. No increase in toxic or potentially toxic compounds. Can agree with CARB different parameters if make sense. Additional requirements may be added.
Specifies test procedures, analysers. Hot and cold tests (or sometimes only hot), durability similar to retrofit plus doesn't harm engine

The applicant shall initially submit a proposed test protocol to the executive officer or designee. The proposed test protocol shall include:

- criteria pollutant and toxic emissions sampling and analysis consistent with the requirements of the procedure;
- test data showing that the candidate alternative diesel fuel parameters as shown below;
- test data showing that the fuel to be used as the reference fuel meets the appropriate specifications;
- the identity of the entity proposed to conduct the tests;
- reasonably adequate quality assurance and quality control procedures

References criteria pollutants and sampling methods consistent with retrofit test
Describe the applicability
General description of fuel characteristics, properties, formulation and chemical composition. Including:
1. Identity, chemical composition, and concentration of fuel additives
2. Sulphur content
3. Total aromatic content
4. Total polycyclic aromatic hydrocarbon content
5. Nitrogen content
6. API gravity (density)
7. Distillation temperature distribution information, initial boiling point (IBP),
8. 10% recovered (REC), 5O% REC, 90% REC, and end point (EP)

Info on how may affect engine performance, wear, and safety must be provided. Must specify the following:
1. Viscosity (engine performance)
2. Fuel volatility (engine performance)
3. Ignition quality (engine performance)
4. Fuel operating temperatures (engine performance)
5. Engine wear tendencies (engine wear)
6. Corrosion (engine wear)
7. Lubricity (engine wear)
8. Fuel flash point (safety)
9. Compare with selection of reference fuels.

Appendix 3 Certification testing issues - drive cycle vs bench test

Current European legislation requires light-duty vehicle (<3.5 tonnes) homologation tests for emissions and fuel consumption on a chassis dynamometer over the New European Drive Cycle (NEDC). Whilst the appropriateness of the NEDC to represent real world conditions might be questioned, determining the benefits of retro-fit technologies when applied to light duty vehicles can be easily quantified by testing to homologation test procedures.

The situation for commercial vehicles with Gross Vehicle Weight (GVW) over 3.5 tonnes is fundamentally different. Due to the wide variation of engines, chassis and body configurations employment of a “whole vehicle” homologation approach is complex and expensive. Engines are therefore homologated for emissions on an engine dynamometer or test bench. From the introduction of emissions homologation up to Euro 2, diesel engines for vehicles over 3.5 tonne GVW have been subject to testing on an engine dynamometer to the 13-mode steady-state test, commonly referred to as Regulation 49. From Euro 3 onward (1999/96/EC) this test has been replaced by the ESC (European Stationary Cycle) with revised power/torque/speed weighting and has been accompanied by the ELR (European Load Response test), and European Transient Cycle (ETC) for gas fuelled engines and engines fitted with exhaust aftertreatment. The ETC test is mandatory for all diesel fuelled engines from Euro 4.

The ETC cycle was produced from real world drive cycle data collected from vehicles driven on European roads. The ETC test includes a highly transient phase and is arguably more representative of real world performance than the 13-mode test. However, the application of the ETC cycle to the engine test bench has produced a stylised test protocol which has no vehicle dependent inertia component (ie vehicle mass) and does not allow or promote the development of whole vehicle system calibration for the optimisation of driveability and emissions.

The emissions reduction efficiency of a DPF is independent of whether it is tested on an engine dynamometer or whole vehicle chassis dynamometer.. The use of either the ESC and/or the ETC test protocols are therefore appropriate for the determination of DPF particulate removal efficiency. VERT specifies a variation of the ISO-8178 8-mode steady-state test as part of its approvals. The VERT procedure is the most scientifically rigorous of all verification test protocols in terms of filter efficiency and the impact of secondary emissions such as NO_2. VERT specifies regeneration methods for each verified filter but it does not involve itself with verifying the means and conditions of regeneration for each application which is the system supplier’s responsibility to define and demonstrate. However exhaust back pressure monitoring and logging is a component of the required 2000 hour durability test.

However, it is well established that, at least for continuously regenerating and catalysed trap systems, exhaust temperatures above around 250°C are needed to promote oxidation of soot alongside favourable NO_x:soot ratios (in the order of 20:1). These conditions can be affected both by appropriate application of the engine to the vehicle and appropriate vehicle duty cycle.

Therefore it is considered that a verification test for DPFs should determine both the effectiveness of the filter in particulate removal and the influence of the vehicle characteristics and duty cycle on the system’s ability to regenerate.

SCR, as well as DOC and EGR to a degree, are very much cycle dependent. SCR systems depend on favourable exhaust conditions for NOx reduction. Exhaust temperatures below 200°C will, for instance in the case of urea based systems, negate any NOx reduction.
It is well documented that duty cycle influences the level of pollutants emitted, and the exhaust temperature experienced. Also, certain duty cycles, for instance refuse collection vehicle operation, may not promote high enough exhaust temperatures to enable correct operation of SCR or adequate regeneration of DPF systems. In any verification test it is therefore important to be able to monitor the exhaust temperature over the cycle to ensure that conditions are favourable for NOx reduction and/or DPF regeneration.

Any NOx scheme should be based on chassis dynamometer testing on agreed cycyle(s) representative of vehicle operation. If NOx abatement systems are only verified on the engine test bench, the exhaust temperatures experienced may be higher than those experienced in operational service, potentially allowing certification to applications which will not benefit from the technology.

There are therefore fundamental decisions to be made in relation to the test protocols to be adopted within verification and certification schemes. We propose that if a new scheme is developed, it should include that:

1) Ideally, DPF testing should be on a chassis dynamometer with appropriate agreed cycle(s) to ensure that regeneration is appropriate to the application
2) Alternatively, DPF testing could be on a bench with a test that seeks to validate the means of regeneration, the conditions under which regeneration takes place appropriate to the application of the system to the vehicle and its intended use.
3) DPF testing should avoid being based on purely a demonstration of filter efficiency (and other emissions)
4) Any non-DPF procedure (eg SCR, EGR, DOC) should be based on agreed test cycle(s), to seek to establish the degree of emissions reduction, validate the conditions under which reduction takes place and the appropriateness of the application of the system to the vehicle and its intended use.

Therefore there are the following questions:

1) What test type should be used for DPF ?
2) Which cycle(s) should be used for DPF (if relevant) and other technical measures?
3) How should the specific details of the test results be reflected in the approval certificate?

Appendix 4 Further details with controlling NOx compliance

In-use compliance of retro-fit systems fitted to on road diesel engines is an important aspect where LEZs, financial or other incentives are used to safeguard against removal of the equipment, failure of the equipment or failure of the operator to fill with the required additive.

PM compliance

A few existing incentive schemes e.g. UK Reduced Pollution Certificate (RPC) employ an initial test in the form of a free acceleration smoke (FAS) test for DPF fitted vehicles, and gas analysis for gas vehicles, to register the vehicle as being fitted with an approved DPF, followed by yearly inspection with in-service emissions tests as per the initial test as well as a visual test. A DPF will function correctly at least in terms of PM reduction if it is not damaged. If the DPF is blocked due to lack of re-generation, no particulate will be emitted, therefore complete blockage is fail safe as far as PM emissions are concerned. The FAS test will not pick up whether regeneration is being properly managed, but exhaust back-pressure sensors, if required in the certification of the device, should safeguard against malfunction. The FAS test can therefore be a satisfactory test for PM devices.

NOx Compliance

There is currently no test for NOx compliance which would allow in-service inspection of retro-fit EGR and SCR systems. Compared to a DPF both of these systems are complex and prone to malfunction and unreliability. Both require more than a FAS test to confirm correct operation.

In-use operation

With SCR systems there may be and incentive for the driver to try and avoid filling the urea tank to save cost. Options to mitigate against this include

- A simple fluid level sensor with a warning alarm at low levels would be present in any system.
- Engine torque could be electronically limited if there is no urea available. However, this is unlikely to be a practical approach for retrofit due to access needed to interact with the engine management system. There may also be serious safety and liability issues associated with this approach.
- Other options include making it impossible to restart the engine when the urea level is low. Again this does not appear a practical option.

Failure or disconnection of a sensor will normally be detected by the electronic control system (ECU) and the system shut off and a Malfunction Indication Lamp (MIL) activated. However, if a sensor is still connected but its inputs tampered with the system can be fooled. Removal of and damage to system components should be apparent and would be detected by the various sensors. OEM systems will include diagnostics to cover failure and tampering. These should also be included in retro-fit systems, and would allow checking of correct operation of the device.

In-use inspection

The in-use inspection regime needs to be able to determine the system is working correctly

A number of approaches are possible:

- Ensure that all components are present and functioning correctly. Any malfunctions are indicated by a MIL and there is a system to log this and action is documented based upon it. Inspection of the malfunction and rectification log would form part of the annual test and inspection.
- In-use testing via a chassis dynamometer. As the NOx output from an engine depends upon speed and load, and therefore exhaust temperature it is necessary to test the performance of an SCR system under controlled loaded conditions. Ideally, such testing should be done on a chassis dynamometer with full emissions analysis capability. The test could be carried out over a cycle appropriate to the vehicle operation or more simply over a few steady state points similar to the ESC. A less sophisticated (and therefore cheaper) dynamometer facility would be needed for steady-state tests but would not offer the level of confidence in the result that a full facility could provide. It is likely that to test every vehicle this way on a yearly basis would be prohibitively costly due to the cost of each test and time out of service. Another approach could be to use Conformity in Service (CiS) testing to check a representative sample of systems in service. Vehicles would be taken out of service and tested on a full heavy-duty dynamometer facility. The number of vehicles tested per year would be based on a statistically robust analysis of systems sold.
- In-use testing on-road using portable emission analysers. This would require hooking up a portable emissions lab to the vehicles and conduction full emissions tests on the road. This approach is carried out by the USEPA. Such testing would avoid the need to test the vehicle in a full chassis dynamometer facility, with its consequential long time out of service. However due to lack of control of test conditions e.g. traffic, weather etc. road testing tends to offer lower levels of repeatability so this method is likely to provide less confidence that the system is working correctly than when tested on a chassis dynamometer. The "road emission footprint" would also need to be established at the time of system verification.

Conclusion

The overall conclusions are:

- Inclusion of a NOx sensor into the system for on board diagnostics (OBD) is recommended for retro-fit SCR, and possibly EGR systems. It is recognised that availability and reliability of appropriate NOx sensors is still an issue but we would expect this to be resolved by 2008 when they will be a part of OEM systems due to the development of the OBD diagnostic systems and codes, both by OEMs and if required, through a retrofit certification scheme
- The feasibility of statistical sampling based Conformity in Service testing utilising an appropriate heavy-duty chassis dynamometer as part of the verification and compliance programme should be examined.

Appendix 5 Issues for the technical measures guidance

1. Include reference to the state aid guidance.
2. The retrofit certification system can form the main reference for BAT reference documents – see certification section – and be used by MS and others to encourage use of BAT in transport, through mechanisms such as requiring BAT in public and best practice tenders.
3. The guidance could link to web-resources including the retrofit scheme, BAT reference documents, relevant EU guidance, information sharing resources (section 13) and other useful sites via a guidance webpage.
4. Illustrate the types of national barriers that should be reduced, and enabling legislation types that should be encouraged, and the situations where each type is relevant.
5. Outline clear guidance and long term strategy on the use of technical measures to reduce emissions.
6. Encourage incorporation of environmental impacts, clean fuels use and energy savings in the tender evaluation process[1]. Possibly providing emissions policies that public bodies can include in their procurement and contract systems, based on BAT principles.
7. Encourage the use of incentives and mechanisms that have worked
8. Encourage use of a technology neutral position. Requiring, e.g. a 90% PM emissions reduction or a retrofit to a very low PM value from a stated start, usually requires a DPF, but does allow other options, such as re-engining.
9. Either point to existing decision tools[2] to decide between different technologies, or develop a tool that allows the user to input the different situation in each MS.
10. Recommend that cities/MS set minimum emissions standards at a local or national level where needed – i.e. LEZs where needed.
11. If financial incentives are given, they given they should:
    - 11.1. be sufficiently stable to allow manufacturer and operator investment
    - 11.2. include ongoing costs e.g. training, operational costs and maintenance
    - 11.3. ensure that when funding is removed the situation is managed to avoid sudden increases in costs and drop in adoption
    - 11.4. be carefully targeted and with clear guidelines if funding is not intended for the whole fleet
    - 11.5. consider including cheap loans for purchase of technical measures
    - 11.6. avoid being too bureaucratic
    - 11.7. take care that they do not inflate prices
12. Guidance on indexing the differentiation of road charges in respect of emissions (NOx, PM, CO_2) to provide direct link to emissions rather than categories of vehicle, keeping the metrics technology neutral. The certification system may make this easier. The metric could be e.g. emissions per vehicle km.
13. Give world-wide examples of best practices, or references to where they can be found
14. Encourage governments to reward implementation of best industry practices, through e.g. sustainability awards
15. Encourage politicians at all levels to lead the process by providing support.
16. Encourage the increase of gas/biogas refuelling by investing in local biogas plants works
17. Encourage the increase of gas/biogas refuelling by
    - 17.1. investing in local biogas plants works
    - 17.2. supporting liquid natural gas (LNG) filling stations on motorways
    - 17.3. encouraging natural gas refuelling directly from the high pressure mains with compressors and high pressure storage

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[1] UIPT and LCEI guidance already exists on this for bus operations, and could be linked to
[2] E.gs include OPITBUS and STARBUS from ADEME, and those via www.miljofordon.se

18. Encourage MS to provide public natural gas refuelling stations at least every 200km along major motorways to help meet the target of 2% natural gas vehicles by 2010. Cost per station would be ~ € 300 000.
19. Encourage MS to have more co-operation from Government Industry and Transport departments, and formalise links between air quality and transport plans.
20. Have long term funding plans for transport, to remove the problems associated with short terms changes in the level of funding and technical focus.
21. Encourage the consideration of fuel choice based on an in-depth economic and ecological ("well-to-wheel") study, taking local circumstances into account. Possibly include methodologies to estimate this.
22. The need to stimulate the existing public awareness and interest for air quality and cleaner fuels/technology.
23. Develop a means of calculating fleet average emissions and a classification system to categorise the emissions from a fleet. This can form the basis of a fleet emissions standard. E.g. Sweden and California.
24. Develop a standard / award / kite mark for organisations and companies that allows these bodies to publicise their compliance with the highest standards, based on BAT or fleet emissions standards.
25. Encourage manufacturers of technical measures to provide good backup services for their products.
26. Guidance to Operators:
    - 26.1. Report on their overall energy use and performance
    - 26.2. Recognise that additional comfort must be compatible with energy savings
    - 26.3. Devote more effort and resources to the training of driving personnel in energy saving, environmentally friendly driving styles
    - 26.4. Information campaigns on energy issues and fuel choice to attract future customers

Appendix 6 Technical measure details

Assessment of the impact on costs and emissions of technical measures on existing heavy duty vehicles and captive fleets

Annex 1 – Technical review

One of the first tasks undertaken during this project has been to gather information by means of a questionnaire provided to stakeholders and a literature survey, to determine:

- What technologies are available
- What benefits are conferred, primarily in terms of regulated emissions (CO, NOx, VOCs, PM_{10}), but also in terms of Greenhouse Gas Emissions and most problematic non-regulated emissions such as PM in number, NO_2, N_2O, attrition residues e.g. Pt, Va etc
- The capital and operational costs of the technologies identified

Results from a detailed questionnaire sent out by DG Environment and the team to the relevant industries to collect technical evidence on the available technologies for the reduction of air pollutant emissions from existing vehicles were collected at the start of this project.

A detailed review of the questionnaires has been undertaken and the data and information developed into a source document.

As a parallel activity published information on the technologies represented by the questionnaires returned has been reviewed in order to validate the responses provided through the questionnaires. This has included many technical papers and reference to California Air Resources Board (CARB), United States Environmental Agency (USEPA), BAFU/SUVA and VERT lists of certified measures. Measures additional to those represented by the questionnaire responses have also been included.

The two sets of information were combined, reviewed by experts within the team, and peer reviewed by a number of independent experts.

Measures reviewed

The purpose of the project is to define concrete policy proposals at EU level, which could help to support the most promising technological options. In particular, the feasibility of a common system at EU level for vehicle certification that takes on board improvements of existing vehicles, in the context of Low Emission Zones, charging systems, economic incentives, public procurement policies, etc.

Against this context the following measures have been reviewed:
Exhaust emissions retro-fit measures

- Diesel Oxidation Catalyst (DOC)
- Diesel Particulate Filter (DPF)
- Exhaust Gas Recirculation (EGR)
- Selective Catalytic Reduction (SCR)
- Lean NOx Traps (LNT)
- Measures to reduce impact of idle emissions
- Re-engining

Alternative liquid fuels

- Di-methyl-ether (DME)
- Ethanol
- Fatty Acid Methyl Esters (FAME)
- Synthetic Diesel (Fischer-Tropsch)
- Diesel Water Emulsion (DWE)

Alternative gaseous fuels

- Natural Gas
- Bio-methane

Complimentary measures

- Low Ash Lubricants
- Closed Crankcase Ventilation systems

Other measures

- Fuel Additives
- Retro-fit hybrid drives
- Low Viscosity Lubricants
- Low Rolling Resistance Tyres

An overview of these measures and their respective costs and benefits is provided below

Exhaust Emissions Retro-fit Measures

Diesel Oxidation Catalyst (DOC)

Heavy Duty diesel engines up to Euro IV level have generally achieved emission reductions through engine modification. For light duty vehicles (including those used as taxis) oxidation catalysts have been in use for some vehicles since Euro II. Over 1.5 million oxidation catalysts have been fitted to new heavy-duty trucks in the US since 1994 although they have not been much used as a retrofit technology in European on-highway vehicles since the 1980's. They are of interest in some of the less developed markets. Whilst they are often applied to older engines which are generally perceived to be unsuitable for particulate filter systems, it should be noted that a Saurer bus of 1948 vintage has been successfully fitted with an HJS trap system.

Operation, control and impact on emissions

As measured by mass within the regulatory filter test protocol, particulate matter (PM), or total particulate matter (TPM) is composed of three major fractions including the carbonaceous particles (soot), the organic particles – soluble organic fraction (SOF), and sulphates (SO_4). Each of these fractions behaves differently over diesel oxidation catalysts. Oxidation catalysts reduce the SOF fraction but have little effect on the carbonaceous portion of PM in the diesel exhaust. This limits the amount of reduction the DOC can achieve. The maximum reduction is dependent upon the magnitude of the SOF in the engine out exhaust and is typically between 20 and 40%. The sulphate fraction of diesel particles (SO_4) is increased in the DOC due to the oxidation of SO_2 with subsequent formation of sulphuric acid. Under certain conditions, however, the SOF decrease can be more than offset by an increase in sulphate PM, leading to an overall increase in TPM emission, therefore low sulphur fuels and special catalyst formulations are necessary to limit the formation of sulphate particles from sulphuric acid in the exhaust gas.

Diesel engines have inherently low CO and HC emissions which can be further reduced by application of a DOC. DOCs have no impact upon overall NO_x emissions. However, DOCs are known to increase the proportion of NO_2 in the exhaust. NO_2/NOx ratios of 10% have been noted at around 220°C exhaust gas temperature rising to ratios up to 50% in the range 300°C - 350°C.

A further concern is in regards to so called ultrafine particulate emissions below 1000nm. From work carried out during the UNECE Particulate Measurement Programme, measurement for particle number (PN) may be introduced in Euro 6. It could be expected that particle number counts downstream of DOCs would be at least equal to that in engine pre-catalyst exhaust and most probably higher in the ultrafines sector due to sulphate formation.

Additionally, the presence of precious metal emissions, notably platinum are detectable in the exhaust.

Fuel requirements

Generally, oxidation catalysts can be used with fuels up to 500ppm sulphur, but some of the sulphur in the fuel will be converted to sulphate which also contributes to PM emissions. The amount of sulphate formed depends on the strength of the oxidation catalyst and the gas temperature. Sulphates will form at around 350°C. Catalyst formulations have been developed which selectively oxidise the SOF whilst minimising sulphate formation. Current market fuels with sulphur levels of 50ppm or lower present no barrier to the use of oxidation catalysts and generally allow higher levels of PM reduction.

Operation and Maintenance

Oxidation catalysts have been retro-fitted to over 750,000 on-road and off-road vehicles worldwide. Oxidation catalysts are essentially maintenance free up to any need for replacement and, if properly applied present little or no impact on fuel consumption (<0.5%). However, the increased presence of sulphuric acid in the exhaust can increase corrosion of silencers leading to earlier replacement.

Costs

DOCs cost between €350 for a small replacement catalyst-silencer to €1500 for a full modular system on an 8 litre engine fitted to large vehicle. Cost is dependent on size, volume, configuration and degree of engineering. Large fleets in the order of 100 or more can promote up to 20% cost reduction. Costs vary also with content of platinum which is increasing in cost on the market, and its partial substitution by palladium.

There is no significant impact on operational cost, other than ultimate replacement.

Diesel Particulate Filter (DPF)

Diesel Particulate Traps (DPF) primarily comprise a filter through which the exhaust gas passes whilst the particulate material is deposited within the filter. As the filter becomes more loaded its resistance to flow increases requiring it to be cleaned of particulate matter or “regenerated”.

Operation, control and impact on emissions

A number of different filter materials have been employed in diesel particulate filters. These include fibre wound cartridges, knitted silica fibre coils, ceramic (cordierite) and silicon carbide, ceramic foam, wire mesh and sintered metal structures. Perhaps the most common filter employed for heavy-duty automotive applications is the high efficiency wall-flow cordierite or silicon carbide filter. These filters have been demonstrated and certified to give particulate mass reduction of greater than 99%. They also demonstrate outstanding reduction of all sizes of solid particles 10-1000 nm in the order of 99%.

Regular and efficient regeneration of the filter in service is a key function of its continued efficient operation. There are a number of methods employed, of which the principle methods are described below;

- Passive regeneration diesel particulate trap. Base or precious metal catalyst applied to the filter surfaces reduces the ignition temperature required to oxidise the accumulated particulate matter.

- Continuously Regenerating Trap® (CRT®) diesel particulate filter system comprising an oxidation catalyst followed by a particulate filter. The oxidation catalyst placed upstream of the filter oxidises nitric oxide (NO) to nitrogen dioxide (NO_2). The NO_2 reacts with the accumulated particulate and reduces the temperature required to regenerate the filter. In some application the filter may also be catalysed (CCRT®)

- Fuel borne catalysts employing a fuel additive (normally iron, cerium or platinum based) which is either injected into the fuel line or dosed into the vehicle's fuel tank. The soot emitted from the engine becomes impregnated with catalyst. The catalytic effect lowers the temperature required for combustion of the accumulated particulate matter.

- Throttling of the intake air to one or more cylinders can increase exhaust temperature thus initiating combustion of the accumulated particulate matter.

- Post top dead centre (TDC) fuel injection into the cylinders introduces unburned fuel into the exhaust gases. This can also be effected by injection into the exhaust system. Oxidation of the fuel within or upstream of the filter can then be used to combust the accumulated particulate matter.

- Fuel burners or electrical heating elements within or upstream of the filter can be used to assist combustion of the accumulated particulate matter.

- Remote "off-board" electrical heaters can provide hot air to assist combustion of the accumulated particulate matter.

- Whilst not strictly an on-board regeneration process, some systems simply replace the filter element with a new or cleaned filter.

Currently, the most widely used systems for retro-fit heavy-duty automotive applications are the passive regeneration, continuously regenerating and fuel borne catalyst systems. It should be noted, however, that in Switzerland the largest retrofit activity has shown an increase from 25 to 35 % of active filter systems (burners, catalytic burners, electric heating etc)

Whilst filters with active regeneration systems can be applied to all types of engines, both passive regeneration and continuously regenerating systems are generally applied to heavy-duty engines Euro 1 and later. Both types of system do not nominally impact upon total NO_x emissions although there is some indication of a small NO_x reduction, possibly through a slight increase in internal exhaust gas Recirculation (EGR). However systems with very strong catalytic action can increase NO_2 significantly. NO_2/NOx ratios of 10% have been noted at around 200°C exhaust gas temperature rising to ratios up to 50% in the range 300°C - 350°C. With CCRT® ratios of about 60% are reported. This is of concern, particularly in inner city areas where a significant proportion of the population will be exposed to primary NO_2. As part of its control equipment verification programme CARB has proposed a post-control NO_2 emission limit to be introduced from 2007, applicable to both new and existing verifications. The new limit is defined as a maximum incremental increase of 30% over the baseline NO_2 emission level to become 20% from 2009.

Continuously Regenerating Trap® systems require a NO_x:soot ratio 20:1 and min exhaust temperature of 250°C to regenerate. Systems employing fuel borne catalysts have limited impact upon NO_x. Nor do they increase NO_2 emissions, in some cases substantially reducing NO_2. These systems are also more suitable for older pre-Euro1 engines.

Active regenerating systems without oxidation catalyst support using precious metals do not increase NO_2 and therefore may increase in population in future.

Diesel engines have inherently low CO and HC emissions. These are generally further reduced by over 80% by application of passive, continuously regenerating and fuel borne trap systems although it should be noted that FBC systems do not reduce CO and HC unless the system incorporates a DOC.

Fuel requirements

Sulphur in fuel significantly affects the performance of catalysis based DPFs which work best with sulphur levels of less than 50ppm. Passive systems appear more sulphur tolerant than continuously regenerating systems and systems employing fuel borne catalysts have been successfully demonstrated with sulphur levels of 500ppm.

Operation and Maintenance

In the UK the whole of the London bus fleet is now equipped with diesel particulate traps. Whist initially there were a number of reliability issues, over the past 5 years, since introduction, maintenance and reliability has improved. The consequence of this implementation are severe regarding NO_2:NO_x ratio which was multiplied by 3 between 2002 and 2006; also the number of hours per year exceeding 200µg/m^3 in Central London has increased from about 60 in 2001 to close to 600 in 2004; in 2010 this number of events is required to be lower than 18.

In Sweden more than 4,000 buses have been equipped with passive filter systems.

In Switzerland more than 15,000 onroad and offroad vehicles are equipped with DPFs with an increasing % of active systems. At least 80,000 buses worldwide and 60,000 fork lifts are DPF-equipped. (A total of 200,000 retrofits is estimated by TTM).

OE-applications are now in excess of three million.

Diesel Particulate Traps can be fitted in conjunction with exhaust gas recirculation (EGR), selective catalytic reduction (SCR) and Lean NOx traps to make significant reductions in NOx and PM levels. Engines equipped with combined SCR and DPF systems can make reductions of 60-80% NO_x and over 90% PM as long as the duty cycle can promote high enough exhaust temperatures.
The effect on fuel consumption is generally accepted to be around 1%. However, this can rise to 3% or higher if regeneration is insufficient.
Diesel Particulate Traps therefore require regular cleaning. This involves removal of the filter from the vehicle, baking in a kiln and washing to remove residual ash. The cleaning frequency is dependent on duty cycle and mileage. Typical manufacturers recommendations are:

- Trucks – once per year
- Buses – twice per year
- Fire tenders, Refuse vehicles – four times per year

The use of lubricating oil with low sulphated ash content should always be considered in association with DPF operation.

Costs

CRTs and passively regenerating DPFs cost from €3000 to €7000 depending on vehicle size and complexity of the application/engineering. Largest single cost is the filter element which would reduce with volume. However another significant cost is platinum which does not reduce with volume.

Systems employing fuel borne catalyst cost from €3000 to €10000 depending on vehicle size and complexity of the application/engineering and volume required.

For OEM implementation cost could reduce to €6,000 per vehicle

Cleaning of filters costs in the order of €300 to €350. Other estimates place the cost as high as €900 Euro if sent in back to supplier. This is considered high.

Exhaust Gas Recirculation (EGR)

Retrofitting exhaust gas recirculation on a diesel engine offers an effective method of reducing NOx emissions. Both low-pressure and high-pressure EGR systems exist. The high pressure route is favoured by OEMs but low-pressure is used for retrofit applications because it does not require fundamental engine hardware modifications. However, it is only applicable for use in urban operations.

Operation, control and impact on emissions

EGR involves recirculating a portion of the engines exhaust back to the charge air inlet of turbocharged engines, or intake manifold, in the case of naturally aspirated engines. In most systems an intercooler lowers the temperature of the recirculated gases. The cooled recirculated gases have a higher heat capacity than the normal ambient air and contain less oxygen, thus reducing combustion temperature and inhibiting NOx formation. However, due to the NO_x:PM trade off relationship, higher PM engine out emissions are produced which are usually reduced by use of a DPF. Recirculated exhaust gases are usually taken from downstream of the DPF so ensuring that large amounts of particulate matter are not recirculated to the engine which could result in excessive lubricating oil loading. However, in the case of naturally aspirated engines the pressure balance between the exhaust taken from downstream of the DPF and the intake air conditions will need to be favourable to ensure recirculation. EGR systems are capable of achieving NO_x reductions of between 40 and 60%.

An advantage of EGR is that it does not require additional fluid or the related distribution network as is required with SCR systems (see below). However it has the disadvantages of slight reduction in vehicle performance, slight increase in fuel consumption and increased maintenance of engines. There is also a potential risk of accelerated engine wear which needs to be considered.

Operation and Maintenance

Demonstration on two Euro 2 double deck buses in the UK has shown NO_x reductions of 54 and 48% over the standard Euro 2 bus. These reductions were accompanied by increases in fuel consumption of 7.5 and 1.1%

Results from FTP engine dynamometer tests presented by the system supplier at the 2003 SAE World congress showed NOx reductions of 46 – 58% over Cummins 2000MY and International 2001MY engines. These reductions were accompanied by a 2% increase in fuel consumption.

Costs

The cost of retro-fitting an EGR system to a truck or bus ranges from €14,000 to €16,000 depending on vehicle size and complexity of the application/engineering.

Selective Catalytic Reduction (SCR)

SCR systems have been applied to stationary sources for many years and with the advent of Euro IV emissions regulations are becoming more prevalent as OEM fit equipment on heavy-duty vehicles. Applying SCR to diesel powered vehicles provides simultaneous reductions of NOx, PM and HC emissions.

Operation, control and impact on emissions

SCR systems use a metallic or ceramic wash-coated catalysed substrate, or a homogeneously extruded catalyst and a chemical reductant (ammonia) to convert nitrogen oxides to molecular nitrogen and oxygen in an oxygen rich environment as found in diesel engine exhaust. In Europe, the chosen route of engine and vehicle manufacturers is to use aqueous urea solution with 32.5% ammonia as the reductant. This is also used for retrofit applications, although some systems use liquid ammonia as a reductant. Liquid ammonia is used at 16% concentration to achieve the same effect per litre as urea.

Both open loop and closed loop systems are available. Open loop systems use an algorithm to determine the amount of reductant required based on engine speed, exhaust temperature, load etc. Closed loop systems are sensor based. SCR systems can reduce NOx by up to 85% although 60 – 80% is typical for retro-fit systems. The level of conversion depends not only on careful matching of the system to the engine but ensuring that the vehicle is matched to the duty cycle. Experience in London has demonstrated that it is feasible to maintain exhaust temperatures in excess of 300°C in normal operation.

HC emissions can be reduced by up to 80% and PM emissions by 20 – 30%. It should be noted that, as with diesel oxidation catalysts, principally only the SOF is reduced, leaving the carbon essentially unaffected. However, there is possibly some soot reduction due to presence of NO_2 and low space velocity in the catalyst. Performance is enhanced by the use of low sulphur fuel which is also a requirement when the system is fitted with a CRT®.

The potential for "ammonia slip" is a characteristic of SCR systems. If an additional catalyst is used downstream of the main SCR system to convert ammonia, this can result in increased N_2O emissions. N_2O is a greenhouse gas, 310 times stronger than CO_2.

OEMs have been able to meet Euro 4 emission limits with SCR and no additional aftertreatment for PM reduction, resulting in Euro 4 vehicles having higher PM and particle number emissions than Euro 3 engines with retro-fit DPFs.

For retro-fit applications SCR systems are usually fitted in conjunction with a full flow DPF, providing high levels of PM and ultrafine particle reduction as long as the duty cycle can promote high enough exhaust temperatures. SCR is not active when inlet temperature drops below 200°C as documented by in SAE paper 2005-01-1862. NO_x and therefore NO_2 reduction is nil in this temperature range.

Fuel requirements

Combinations of SCR and DPF require fuel with sulphur levels of less than 50ppm. SCR alone does not require reduced sulphur content.

Operation and Maintenance

Retro-fit SCR systems are an emerging technology option. Over 100 mobile SCR retro-fit systems have been fitted in the US since 1995 and several hundred systems have been retro-fitted to heavy-duty vehicles in Europe.

Costs

The estimated cost for city bus with Euro 3 8 litre engine is in order of €10,000 for low volumes anticipated (without DPF) or €15,000 with DPF

Lean NOx Traps

Lean NOx traps (LNT) are currently the technology of choice for treating the NO_x emissions from lean-burn gasoline engines and is still an emerging technology for removing NO_x in lean diesel exhaust.

Operation, control and impact on emissions

In LNT technology Nitric Oxide (NO) is catalytically oxidised to Nitrogen Dioxide (NO_2) and stored in an adjacent trapping site as a nitrate. The stored NO_x is removed in a two-step reduction process by temporarily inducing a rich exhaust condition using a pulsed charge in fuelling i.e. using diesel fuel as a hydrocarbon reductant. This gives an advantage over SCR systems of not needing to provide an additional reductant.

NO_x adsorbers employ precious metal catalyst sites to carry out the NO to NO_2 conversion step. The NO_2 is then chemically stored in alkaline-earth oxide as a nitrate. To operate effectively, the NO_x adsorber must remain stable for extended periods, during which time the exhaust environment modulates between rich and lean conditions.

Lean NOx Technology can produce very high NOx conversion efficiencies (70 – 90%) when new. Unfortunately, Lean NOx Traps are drastically poisoned by sulphur dioxide (SO_2) derived from the sulphur in the fuel. This reacts catalytically with oxygen and then with the NO_x storage components, such as $BaCO_3$, forming stable sulphates ($BaSO_4$) and rendering the adsorbing capabilities of the system ineffective. In addition, SO_2 can be catalytically converted to sulphate in the exhaust stream, resulting in higher particulate emissions.

Fuel Requirements
The higher sulphur dioxide concentration in the exhaust, the faster poisoning occurs. LNT is also sensitive to sulphur content of engine oils. Therefore very low Diesel sulphur fuel (<5 ppm – even <1ppm) does not necessarily prevent sulphur poisoning as sulphur content of the lubricant becomes very important and must also be reduced to minimise the poisoning effect. LNT requires regular desulphation strategy. De-sulphurisation requires temperatures in excess of 600 °C, difficult to achieve easily in diesel operation.

Operation and Maintenance

LNT is not considered in the EU due to cost, fuel non-flexibility, efficiency, complexity of control and durability. There is now no LNT development in the EU

Costs
Based on US information the cost to fit a combined LNT+DPF system to a heavy-duty truck is in order of €12,000 to €16,000 including the DPF

Measures to reduce impact of idle emissions from trucks

In the US in May 2001, President Bush issued the National Energy Policy directing EPA and DOT to work with the trucking industry to establish a programme to reduce emissions and fuel consumption from long haul trucks. This programme included an examination of idling fuel consumption and emissions from these vehicles, which, it is estimated have idle times of between 1,500 and 2,400 hours per year.

EPA measured the emissions from a selection of mid-1980’s to 2001 trucks under ambient conditions from 0°C to 32°C. They compared the engine emissions generated whilst maintaining a cab temperature of 21°C. with those generated by auxiliary power units (APU) and direct fired heaters (DFH).

EPA concluded that on average, a typical 1980’s- 2001 model year truck emitted 144 g/hr of NO_x and 8224 g/hr CO_2 and consumes about 3.1 litre/hr of diesel fuel. The use of an APU can reduce idling fuel consumption by 50% to 80% and reduce NO_x by 89% to 94%. The use of a DFH can reduce idling fuel consumption by 94% to 96% and reduce NO_x by 99%.

Whilst these figures do not necessarily apply to European operations it would seem appropriate to examine typical European operations to determine equivalent data.

In California CARB has introduced the Transport Refrigeration Unit (TRU) Air Toxic Control Measure (ATCM) which is designed to use a phased approach over 15 years to reduce diesel particulate matter emissions from in-use TRU and TRU generator sets that operate in California, irrespective of whether they are registered in or out of the state. The TRU ATCM will require in-use TRU and TRU generator set engines to meet in-use performance standards that vary by horsepower range. Standards can be met by:

- Using an engine that meets the required engine certification value
- Equipping the engine with the required level of verified diesel emission control strategy
- Using an alternative technology

Compliance schedule requirements will be phased, depending on engine model year.

EPA has also launched the SmartWay Transport Partnership. EPA focuses on technologies to reduce idle emissions e.g.

- Auxiliary Power Units (APUs) to provide power to the truck when the main engine is switched off.
- Automatic engine idle systems which start and stop the truck engine automatically to maintain cabin temperature or battery state of charge.
- Truck electrification stops to allow trucks to use power from an external source. Each truck will need to be equipped with electrical heating and air conditioning system and inverter.

Costs

Costs derived from EPA and the State of New Jersey has identified costs for some of these measures as follows;
Cost of APU: €5,500
Truck stop electrification infrastructure: €1,870 per truck stop
Electrical heating and air conditioning system and inverter: €1960 per truck

Re-engining / Repowering

Repowering involves replacing an old engine with a more modern one to achieve better emissions performance from an existing vehicle. This can be expensive, so is only likely to be worthwhile in vehicles that are likely to have a long service life, such as refuse collection vehicles, buses and airside vehicles.

Operation, control and impact on emissions

Repowering can lead to reductions of all regulated pollutants, lower fuel consumption and improved reliability, although this can vary significantly from case to case. Replacing a pre-Euro engine with a Euro II engine in a bus could lead to reductions of around 60% for PM and 40% for NOx, depending on duty cycle. However, replacement of a Euro II engine with a Euro III engine may result in no benefit to NOx emissions. In certain cases these have been known to increase. With the inclusion of the European Transient Cycle in the heavy-duty homologation requirements, repowering to Euro 4 would be expected to provide both NOx and PM benefits, although these may not be significant in real world conditions. Reductions in particle number may, however, not be as significant as might be expected and needs to be assessed against emerging data. In all cases it is important to ensure that the new engine will be properly matched to the vehicle transmission. This may require the transmission to be replaced also. Furthermore, repowering older vehicles with newer engines which have electronic control is likely to require the introduction of new power and control sub-systems. Therefore whilst repowering might be attractive for vehicles with long service life, offering a route to extended life, improved reliability and potentially lower operating and maintenance costs, it may prove to incur a high initial cost.

Costs
Typical costs for repowering to Euro III with a heavy-duty engine are in the region of €16,000 to €24,000 for the basic engine and fitting. This cost should be considered against the cost to repower the vehicle on a like for like basis i.e. with a remanufactured engine of the same Euro level. The cost to repower would be increased if the gearbox is also replaced. Costs to repower to Euro 4 have yet to be established.

Alternative Liquid Fuels

There are a number of alternative liquid fuels becoming available, produced by a variety of methods which can be used as blends with conventional diesel or as 100%. The fuels considered are ethanol, biodiesel (or Fatty Acid Methyl Ester – FAME) and synthetic diesel. These fuels share distinct advantages over gaseous fuels:

- No requirement for special distribution infrastructure apart from transport to existing refineries and depots
- Little or no modification to existing vehicles
- Can be used in various proportions as blends with conventional fuels in relation to their availability.

These fuels, when used in blends up to 5% with conventional fuels, have no significant effect upon the energy efficiency of the vehicles. However, blends with oxygenated components tend to produce higher levels of aldehydes than conventional diesel.

Di-methyl-ether or DME does not share the above advantages but is available as a direct substitute for diesel fuel and can be produced in a similar way to synthetic diesel. DME is gaseous at ambient conditions but can be liquefied under moderate pressure. However, compared with the other fuels considered, it requires a dedicated distribution infrastructure and modification to vehicles to allow its use.

Di-Methyl-Ether (DME)

DME is currently used on a very small scale, around 150,000 metric tonnes per year, mainly as an aerosol propellant for the cosmetics industry.
DME is synthesised from syngas, and can therefore be produced from a range of feedstocks. The most likely feedstock in the short term is natural gas, but coal or wood can be envisaged. Asia is considered the first market for DME to break through. DME Development Co is working to validate a direct synthesis process in Japan. China is to start construction of its largest DME project with an annual output of three million tons to reduce rising oil consumption.

Operation, control and impact on emissions
As a fuel for compression ignition engines, DME has very attractive characteristics. It is an oxygenated fuel with 35% wt oxygen with a high cetane number (68), burning very cleanly and producing virtually no particulates. The lower heating value of DME is, however around 66% of conventional diesel fuel. It is also less dense. It therefore requires around 1.49% more fuel per injection stroke when compared with conventional diesel.

In a study on DME as an alternative fuel for diesel engines for CANMET Energy Technology Centre and Transport Canada, Advanced Engine Technology Ltd found emissions of PM were reduced by 75% and NOx emissions by 5.9%. These results were obtained following development and modification of the injection system and engine to run on DME. Further NOx reductions were anticipated through optimisation of injection timing. Methane emissions, however, increased by 24%, admittedly from a very low baseline. THC emissions, mainly unburned DME increased by 237%.
Due to the lower flashpoint and higher vapour pressure as compared with diesel, additional safeguards were needed to minimise the potential for fire or explosion. There are additional concerns regarding compatibility of materials with DME.

In a paper presented at SAE 2006 AVL concluded that as DME combustion is virtually soot free, it would allow high rates of EGR to reduce NOx emissions. Combined with strategies to counter the longer injection durations needed it is considered that DME fuelled engines might be able to meet US 2010 heavy-duty emissions legislation without further exhaust aftertreatment.

Costs

At the time of writing no costs for sales at automotive volumes of DME are available. Cost estimates will be welcome

Ethanol

Ethanol is a well established substitute for gasoline in spark-ignition engines and is now firmly established as an alternative fuel in Sweden where it is used both as a low (5%) blend in all gasoline and as an 85% blend for "Flex Fuel" vehicles. As far as heavy-duty vehicles are concerned it has been successfully applied as 92.5% ethanol plus cetane improver and other additives. This fuel is 50% renewable. The engine used in Sweden is a development of the 9 litre compression ignition Scania engine. Around 600 ethanol buses have been delivered so far. Scania is now developing its third generation ethanol engine, planned to be ready for introduction in late 2007

Operation, control and impact on emissions

The current Scania ethanol engine generation introduced in 1996 reaches Euro 4 levels, which will be required from October this year. Scania will introduce an ethanol bus meeting Euro 5 emissions levels later in 2006

Costs

As with most new or low volume technologies, the additional purchasing cost varies with the kind of contract agreed with the provider.

Stockholm has during the last 10 years paid approx. €10,000 extra per bus, compared to a ordinary diesel bus.

A few factors may influence this price difference:

- economy of scale - currently, Stockholm is almost the only buyer of these buses, except for a few small pilot fleets in Italy, Spain, NL and Poland

- Public Transport buses are generally over-priced - due to the fact that each city requires it's own standard and the series hence are small.

- next generation of ethanol buses, where experiences from first generation should lead to cheaper construction. However this might be reflected in increased performance rather than lower price.

- upcoming emission standards - Euro IV, and especially Euro V will make conventional diesel buses more expensive

Information from the ethanol bus operation in Stockholm showed that the average fuel cost per kilometre of ethanol fuelled buses was between €0.36 and €0.39/km compared with an equivalent cost for diesel of €0.37 to €0.38/km. However this is based on an average consumption of 69 litres/100km of ethanol compared with 41litres/100km for diesel. The cost of ethanol in Sweden is stated as €0.537/litre and diesel as €0.906/litre.

The total operating cost, including maintenance per kilometre was between €0.62 and €0.742/km compared with an equivalent cost for diesel of €0.539 to €0.653/km.

Fatty Acid Methyl Esters (FAME)

Fatty Acid Methyl Esters or FAME, are produced by reacting vegetable oils with methanol. The operation stabilises the oil and makes it suitable for use as a standard diesel fuel component. They can be used without problems in standard diesel engines as blends up to 5% with conventional diesel. They can be used in blends up to 100% but are liable to the formation of gums and are therefore not acceptable as a mainstream product. However, Scania and DAF have recently announced that B100 can be used in its new trucks, subject to meeting EN14214 and adhering strictly to service requirements. Renault also support B30.

Operation, control and impact on emissions

As part of the Particulates programme for DG TREN, Concawe tested a number of fuels. The presence of 5% FAME in 10 ppm diesel showed no impact on PM or NOx. In principle, the presence of oxygen in the fuel tends to produce less soot, which is confirmed by extensive literature. However, FAME has a high boiling range, in the back-end of diesel distillation, and this can lead to higher emissions of hydrocarbons in some cases, particularly under cooler, e.g. city, driving conditions. The overall effect on PM emissions is therefore variable and depends on driving conditions. Whilst biodiesel content in EN590 is limited to 5%, higher percentages (30% typical) have been used for captive fleets.

Results of tests on RME/diesel blends up to 100% reported to SAE in 2005 concluded that RME does not worsen emissions but also provided no significant emission benefits. Despite curtailing soot a DPF is still considered necessary.

Costs

Biodiesel (to fuel standard EN 14214) tends to cost more than regular diesel to produce. Therefore appropriate tax regimes need to be adopted in order to encourage take-up. For instance, in July 2002, to compensate for these additional costs and to encourage the production and use of this fuel, the UK Government reduced the tax on biodiesel by 20 pence per litre. As a result, biodiesel pump prices are now roughly the same as standard diesel.

Synthetic Diesel (Fischer-Tropsch)

Fischer-Tropsch is a generic name for fuel produced from a range of feedstocks via gasification. Feedstocks for Fischer-Tropsch process can be highly varied. The principle source, natural gas (GTL) is convenient but not a future solution. Volumes are limited today but expected to increase significantly before 2020; however its contribution to world demand is expected to be limited to around 4%. Its main use is expected to be as a blending component in conventional diesel but limited volumes may be available for fleet use. Synthetic diesel can also be produced from coal. Sasol has a large production based on gasification of coal and still produces about 160,000 barrels per day of F-T products. Production from biomass provides advantageous life-cycle Green House Gas emissions but supplies are not yet commercially available.

Fischer-Tropsch products are composed almost exclusively of paraffins and olefins. They contain very little aromatic compounds. Furthermore, they are practically free from sulphur, as well as from other compounds that are found in crude oils, such as nickel, vanadium, or nitrogen.

A very important feature of synthetic fuels is their compatibility with existing diesel engines. The only adjustment that may be required is increasing the lubricity of fuel in order to prevent excessive wear of the fuel injection system, achievable using commercial lubricity additives.

Compared with current production diesel fuels, FT diesel is expected to reduce NOx by around 10% and PM by around 25%.

Costs

At the time of writing no costs for sales at automotive volumes of DME are available. Cost estimates will be welcome

Diesel Water Emulsion (DWE)

This fuel cannot be regarded strictly as an alternative liquid fuel, but is placed in this category for convenience of grouping. It is based on homologated Diesel fuel with around 10% water and 1-2% additives (glycol). These additives keep water droplets in emulsion with diameter centred around 700 nm. Water droplets of this size are important to allow diesel droplets vaporisation and emulsion stabilisation during storage

Operation, control and impact on emissions

The water suspended in the fuel creates a cooling effect in the combustion chamber thus inhibiting NOx formation. Lower PM formation is also claimed. This can by as high as 50 % for larger particles but offers no improvement for particles < 100 nm

Compared to Diesel, DWE can reduce NO_X around 10 %, and, if used on its own will not impact upon the NO_x/NO_2 ratio. However, if used in combination with a DOC, the impact on the NO_x/NO_2 ratio will be similar to that for the basic fuel.

Driving conditions are impacted due to power output reduction. This may result in a reduction in fuel consumption

Lubrizol PuriNox is detailed on the EPA list of verified technologies. PM reductions are stated as 16 – 58%; NOx reductions as 9 – 20%.

CARB details three executive orders on its listing of approved technologies. These are for PuriNox, Aquazole and Clean Fuel Technologies. All three fuels are approved at around 15% reduction in NOx and around 60% reduction on PM.

Tests in the UK on a Euro 2 bus as tested on a chassis dynamometer over a cycle representative of bus operation in London showed a NO_x reduction of 13% compared with ULSD. However, this was accompanied with a 10% increase in particulate matter and a slight (<1%) increase in CO_2 emissions.

Tests on a Euro 3 refuse collection vehicle as tested on a chassis dynamometer over a cycle representative of refuse vehicle operation, showed no reduction in NOx emissions when compared with those from ULSD.

The impact of DWE on emissions appears to be influenced by drive cycle and level of engine technology.

Operation and Maintenance

In general, emulsions can be used on all heavy duty vehicles, from Euro1 to Euro3. However emulsions will not solve existing problem or improve deteriorated engines. Injectors and fuel pump have to be checked and in good state, if not they have to be replaced.

For new engine with common rail, manufacturers indicate problems with DWE due to low thermal stability of DWE giving separation of water and fuel, leading to pump seizing. Cavitations problems on injectors can also appear.

For pre-Euro to Euro 3 (without common-rail), durability is equivalent to Diesel. For new engines, manufacturers may reduce or remove warranties when using DWE.

Fuel storage and dispensing infrastructure is identical to standard diesel fuel. Normal practice is to use existing diesel tanks and pumps, although instances are known where the fuel supplier has required tanks and dispenser systems to be cleaned prior to use with DWE.

The fuel can be stored without any degradation for at least four months (but normally a much quicker turnover than this would be expected). Agitation of the fuel to prevent degradation is not necessary.

Costs

The pricing structure of these fuels can be complex and depends on the tax structure of the fuel. The fuel costs more to produce than ULSD. In the UK, for example, the water content of the fuel (around 10%) is exempted from paying tax. This allows DME to sell at roughly the same price as ULSD. However, this will result in an increase in fuel costs of around 10% due to the lower energy density of the fuel. There are similar tax arrangements in France and Italy.

Alternative (gaseous) fuels (CNG, LNG, LPG)

Spark ignition engines, particularly when used in stoichiometric mode and employing three-way catalysts can produce very low emissions. For light-duty applications including taxis gasoline vehicles are available, but these cannot match the durability or fuel efficiency of the diesel vehicles generally used today.

For heavy-duty applications, gaseous fuels, especially CNG, provide an alternative to diesel at least for urban fleets, and CNG bus fleets are in service in some European cities. However, the higher fuel consumption and greenhouse gas emissions associated with spark-ignition engines needs to be considered. The JEC well-to-wheels study shows that the greenhouse gas emissions reductions associated with use of CNG are small, and do not justify its widespread use, but suggests that use in captive fleet markets might be more appropriate. However, the use of bio-methane in natural gas vehicles can bring significant reductions in greenhouse gas emissions.

Replacing or retrofitting a vehicle to run on CNG is expensive, however emission reductions compared with an older diesel vehicle can be considerable. However, diesel vehicles equipped with combined DPF+SCR systems have been demonstrated to give NOx and PM emissions equally as low as CNG vehicles. CNG fuelled vehicles will generally be most attractive where the fleet operator can manage their own fuel supply, since CNG is not expected to become widely available at normal filling stations.

LPG has been primarily used in light-duty vehicles, and its use is not expected to expand significantly.

For long haul applications the use of “dual fuel” engines using a mix of methane gas (typically between 65-85 %) and diesel can be commercially viable. The new generation of electronic controlled systems using closed loop technology operate on equal gas substitution even in low load conditions making bus fleets and refuse vehicles potential candidates.

Operation, control and impact on emissions

A number of dual fuel systems are currently offered, principally in the UK, as retrofit conversion. This involves adaptation of the diesel engines in HD vehicles to run on a blend of methane gas and pilot injected diesel and also requires installation of LNG or CNG tank(s) on the tractor unit with optional additional CNG tanks on any trailer unit. Packaging of these tanks and other system components is non-trivial, particularly if such a system were to be used on an urban bus. The consequent reduction in payload also needs to be considered. The vehicle retains the capacity to run on pure diesel fuel (in areas where refuelling with methane gas is not feasible).

The actual share of methane and diesel respectively to a significant extent depends on driving patterns and diesel injection systems supplied by the manufacturer. HD trucks used in long distance transport are able to achieve a very high share of methane use with average substitution levels of around 70%.

Solutions for Euro 3 (and earlier used emission classes) have been successfully implemented with work on Euro 4/5 diesel vehicles ongoing.

Emissions reduction benefits will differ somewhat depending upon the original vehicle used and the conversion solution used. NO_x may be somewhat reduced, and the vehicle will cause less vibrations and emit less noise. CO_2 emissions will be significantly reduced (with 80 % methane in the form of natural gas and with, in principle, the same engine efficiency in dual fuel mode as in diesel mode, the CO_2 reduction will be around 20 %. Emissions of PM and NMHC will be reduced by some 80 %. As with all natural gas engines the treatment of the exhaust with an appropriate system to convert methane emissions is important. There have been significant studies on particle emissions from natural gas engines. VTT showed that buses equipped with CNG engines produce levels of small particles at least equivalent to CRT equipped Euro 3 diesel engines. However, no data has been obtained on any particle distribution work on dual-fuel engines.

Tests on dual fuel diesel/natural gas engines to the European ESC and ETC protocols have concluded that with the latest technology a Euro 3 diesel engine can be promoted to Euro 4.

Costs

The conversion option has within the EU so far mainly been used in the UK. The complete conversion package, including training of drivers and warranty may end up in the €22-25,000 bracket (dependant on fuel containment packages and sizes). It could be envisaged that these costs could reduce by up to 20% given sufficient production volume.

Net savings on operational costs (much lower fuel costs, marginally increased maintenance costs) could for an 18 tonne truck reach some €0.11/km, for a 44 ton truck €0.13 - €0.19/km, this is dependent on purchase price of diesel and gas and the vehicle's achievable fuel consumption

Maintenance costs are slightly increased due to extra gas filter changes and some small servicing costs for gas injectors; however this is a very small addition. Serious conversion offers will include a warranty on the converted engine. The choice of suitable synthetic lubrication oils is very important as it is necessary to protect the after-treatment in the exhaust, however this adds to the fuel efficiency of the engine and because gas is a clean burning fuel adds operational life to the engine.

One disadvantage faced by natural gas vehicles has been poor resale value. Modern retro-fit dual fuel vehicles can be converted back to pure diesel operation so protecting residual value.

Bio-methane (biogas)

Biogas, produced by the anaerobic digestion of organic waste such as food and animal manure, could be a valuable fuel for road vehicles. This would reduce dependence on imported oil and benefit the environment by providing a disposal option for waste that otherwise might be land filled and reducing emissions of carbon dioxide and methane, which are both important greenhouse gasses. Biogas is firmly established in Sweden where it has found heavy-duty applications in bus fleets and rail traction. As produced by anaerobic digestion the gas has a methane content of about 65%. Before being able to be used in vehicle engines the methane content is increased to around 95% by removal of CO_2 and H_2S and cleaned of other contaminants such as water, grit etc.

The main sources of waste for biogas production are agricultural manure and food wastes. Vehicles equipped to run on natural gas can run on biogas without further modification and produce similar levels of air quality emissions. Biogas fuelled vehicles can reduce CO_2 emissions by between 75% and 200% compared with fossil fuels when measured on a Well-to-Wheel (WTW) basis.

Costs

The availability of cost data for biogas production is poor. Many of the costs are very plant specific depending on the site, other infrastructure required, what feedstocks are being used and so on. Also biogas is often viewed as a by-product from what is a waste treatment process, and so the economics are viewed from the point of view of how much does it cost to treat a tonne of waste. However, as regards the UK, for example, data from Sweden and the US suggest that biogas can be produced and sold in the UK at a cost of between 50-60p/kg, including duty (at the reduced rate of 9p/kg) but excluding VAT, which is comparable to the current price of CNG to transport operators in the UK at around 55p/kg.

Complimentary Measures

Low Ash Lubricants

Lubricating oil characteristics impact upon the effectiveness over time of exhaust aftertreatment systems containing poisons for catalysts e.g. sulfur, phosphorous and ash which builds up in DPF systems, increasing exhaust back pressure and necessitating cleaning.

Tests on a range of oils with different ash content have shown the rate of EBP increase to be 5 times greater with 1.8% ash oil compared with 1% ash oil. This equates to a 2% increase in fuel consumption compared with a 0.4% increase in fuel consumption after 100,000 km. This will provide a proportional effect on CO_2.

Low ash lubricants should be encouraged as part of the supply for diesel particulate filters.

Costs

Cost information for the use of low ash fuels is currently awaited

Closed Crankcase Ventilation Systems (CCV)

In turbocharged heavy-duty diesel engines the engine blow-by gases are traditionally vented via a crankcase breather to atmosphere, usually via a downward directed draft tube. Whilst this system usually employs a rudimentary filter or flame trap, there is potential to release a substantial amount of PM to atmosphere. MECA report that emissions through the breather may exceed 0.7 g/bhp-hr at idle.

Operation, control and impact on emissions

One solution to this problem is the use of Closed Crankcase Ventilation (CCV) where the blow by gases are directed back into the engine intake system via a multi-stage filter designed to collect, coalesce and return the emitted oil back to the engine sump, whilst filtered blow-by gases are returned to the combustion air intake. Typical systems comprise a filter housing, pressure regulator, pressure relief valve and oil check valve.

EPA state in its report on reducing emissions from the US legacy diesel fleet that the use of CCV could reduce total PM emissions (exhaust and crankcase) by 5 – 10% or more. Whilst this figure should be examined against European operational experience, it would seem appropriate to encourage this relatively low cost technology.

Operation and Maintenance

CCV systems have been available as OE fit on heavy-duty engines at Euro 3 level, on some engines, although these appear to optional. There are major retro-fit programmes in the US, notably on school buses as part of the Clean School Bus USA programme. There is currently one system identified on the USEPA list of

verified measures. This is specified in conjunction with a diesel oxidation catalyst. A number of Executive Orders refer to this type of technology on the CARB database
US EPA requires all OEMs to adopt CCV for model year 2007. In Europe this is likely to come into focus for Euro 6.

Costs
Based on US experience the cost of fitting a CCV system to a bus or truck is typically between €350 and €550. Filter elements will need to be replaced at normal oil change intervals.

Other Measures

Retro-fit hybrid drives

Retro-fit hybrid drives are gradually becoming available. Technologies include diesel-electric series hybrid and hydraulic hybrids. They can vary in complexity ranging from simple start/stop systems to fully integrated powertrain systems offering both series/parallel or mixed mode operation, although the more complex systems are unlikely to be offered as retro-fit options.

Operation, control and impact on emissions

The main advantage of hybrid drives is the ability to recover energy spent in start-stop conditions through regenerative braking. The energy is stored in a rechargeable energy storage system (RESS) and can then be released during acceleration from stop.

The main focus of hybrid drives in Europe is as a means of improving fuel efficiency and reducing greenhouse gases. Improvements of 30% have been demonstrated.

The impact on regulated emissions is often expected to be similar to the benefits to greenhouse gas emissions. However, careful calibration of the energy management system is needed to avoid increases in NO_x due to the operation of the power unit being shifted to ranges with higher specific NOx (e.g. outside from the ESC-control range), compared with operation of a conventional powertrain.

The widespread application of start/stop technology to captive fleets operating in an urban environment on a start/stop cycle may offer significant savings in fuel consumption. This technology is extremely cost effective and offers good potential for NO_x reduction.

Costs
Capital cost of these technologies is currently very high. However, depending on vehicle mileage and fuel cost payback can be achieved in 2 – 3 years.

Low Viscosity Lubricants

Engine lubricant characteristics impact directly and indirectly engine emissions and consumption. Oil viscosity (kinematic, dynamic and HTHS) and friction additives are directly linked with engine friction performance, which impacts upon engine fuel consumption and emissions. For example, 20% friction reduction in rings / piston will give around 3-5 g CO_2/km reduction.

Operation, control and impact on emissions

Tests on a range of oils (engine, transmission, axle) indicate that fuel economy can be improved by 2 – 3% with oils with improved and optimised viscosity characteristics.

The impact on other emissions has not been documented but there is the potential to marginally reduce other pollutants, perhaps, but not necessarily, in proportion to fuel savings.

The impact on other emissions has not been documented but there is the potential to marginally reduce other pollutants, perhaps, but not necessarily, in proportion to fuel savings.

Low Rolling Resistance Tyres

Rolling resistance clearly makes an important contribution to the fuel consumption and emissions from a vehicle, although at high speed aerodynamic effects may be more significant.

Operation, control and impact on emissions

Low rolling resistance tyres and wide base single tyres for drive axle of long haul vehicles are available for long haul transportation. These are applicable to all vehicles operating in that sector and at all Euro levels

A fuel saving of between 0.5 and 1.5 l/100km fuel consumption
Wide base single tyres can also be applied to urban buses.

A fuel saving of 1.5 l/100km FC per single 12m bus, 3 l/100km fuel consumption per articulated 18m bus is quoted. This could equate to between 2 and 8% on fuel costs.

The impact of these tyres on other, regulated emissions has not been documented but there is the potential to marginally reduce other pollutants, perhaps, but not necessarily, in proportion to fuel savings.

Fuel Additives

There are a number of hydrocarbon fuel additives marketed which aim to reduce emissions.

The impact of additives is very difficult to determine on a generic basis and can only be determined by extensive fleet trials and emissions tests. Results will be specific to the additive formulation, design of the trial and emissions tests and the age and condition of the vehicles used in the trial.

Furthermore, if the trial is a long term test the effects of seasonal variations on vehicle baseline performance must be considered.

Summary

The technical measures reviewed have been categorised as follows:

Primary measures

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

Secondary measures

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

Other measures

- 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

This does not mean that they are not valid technologies, particularly in many cases in terms of CO_2 emissions.

Primary measures

Exhaust emissions retro-fit measures

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

Alternative liquid fuels

- Ethanol
- Diesel Water Emulsion (DWE)

Alternative gaseous fuels

- Conversions to dual fuel Natural Gas
- Conversions to dual fuel Bio-methane

Secondary measures

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

Other measures

Exhaust emissions retro-fit 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 NO_x emissions
- Synthetic Diesel (Fischer-Tropsch) – due to early stages of production and volume availability, and therefore uncertainties

Other measures

- Conversion to dedicated spark ignition Natural Gas or Bio-methane – due to erosion of air quality benefits compared with, for example, diesel plus SCRT plus DPF, and its relative lower efficiency.
- Fuel Additives (other than FBC) – due to the low impact on PM and NO_x emissions
- Retro-fit hybrid drives – due to their early stage of development, and therefore supply uncertainties
- Low Viscosity Lubricants – due to the low impact on PM and NO_x emissions
- Low Rolling Resistance Tyres – due to the low impact on PM and NO_x emissions

QUESTION FOR WORKSHOP: Do you agree with these conclusions?

The characteristics of the most promising technical measures are shown in Table 1 below.

QUESTION FOR REMOTE FEEDBACK:
Are the data in Table 1 below reasonable for the costs and emissions reductions from these technical measures below? Are there any gaps you can fill?
If not, please send us your views on what it should be with reasons and the evidence for the change.

Summary of technical measures applicable to heavy-duty vehicles and captive fleets

Primary measures

Measure	Vehicle category	Emission standard/age	Emission reductions/changes related to the base case vehicle						Costs		Restrictions, Drawbacks
			NOx	PM	NO2	Fuel cons/ CO2	<1000 nm Solid particles	Other	Capital	Operation	
DOC	All heavy-duty	Pre-Euro: >14 yrs Euro 1: 10 -14 yrs Euro 2: 7 -10 yrs Euro 3: <7 yrs	Zero Zero Zero Zero	-20 to -40% -20 to -40% up to -20% up to -20%	up to 50% up to 50% up to 50% up to 50%	Zero Zero Zero Zero	Risk of increase	CO and HC: typically 80%. 90% with 50ppm Sulphur	€350 (small system) €1500 (large system)	Zero Zero Zero Zero	Sulphation (corrosion), NO2 emissions, PT emissions, other secondary emissions. Use as low sulphur fuel as possible to reduce effects
DPF (CRT®, catalysed)	All heavy-duty	Euro 1: 10 -14 yrs Euro 2: 7 -10 yrs Euro 3: <7 yrs	-2 to -4% -2 to -4% -2 to -4%	>99% >99% >99%	up to 50% up to 50% up to 50%	<+1% <+1% <+1%	>99% >99% >99%	CO and HC: typically 90%.	€3000 (small system) €7000 (large system)	Cleaning costs: Trucks - €350/yr Buses - €700/yr RCVs - €1400/yr Up tp 1% increase in fuel cost	Needs low sulphur fuel (<50ppm) Some older DPFs increase NO2
DPF (partial flow)	All heavy-duty	Pre-Euro: >14 yrs Euro 1: 10 -14 yrs Euro 2: 7 -10 yrs Euro 3: <7 yrs	Zero Zero Zero Zero	up to 50% up to 50% up to 50% up to 50%	up to 50% up to 50% up to 50% up to 50%	Zero Zero Zero Zero	Potentially zero	CO and HC: typically up to 80%. 90% with 50ppm Sulphur	€3000 (small system) €7000 (large system)	Will require cleaning but possibly at lower frequency than full flow filter	Lower PM reduction, potentially minimal impact on ultrafines.

DPF (FBC)	All heavy-duty	Pre-Euro: >14 yrs Euro 1: 10 -14 yrs Euro 2: 7 -10 yrs Euro 3: <7 yrs	-2 to -4% -2 to -4% -2 to -4% -2 to -4%	>99% >99% >99% >99%	Zero Zero Zero Zero	<+1% <+1% <+1% <+1%	>99% >99% >99% >99%	CO and HC: If fitted with oxycat typically 90% with 50ppm Sulphur fuel. Can reduce to 30 – 40% with 500ppm fuel.	€3000 (small system) €10000 (large system)	Cleaning costs: Trucks - €350/yr Buses - €700/yr RCVs - €1400/yr Up to 1% increase in fuel cost	Requires fuel additive and dosing system. Best with low sulphur fuel (<50ppm)
DPF (active regeneration)	All heavy-duty	Pre-Euro: >14 yrs Euro 1: 10 -14 yrs Euro 2: 7 -10 yrs Euro 3: <7 yrs	-2 to -4% -2 to -4% -2 to -4% -2 to -4%	>99% >99% >99% >99%	Zero Zero Zero Zero	<+1% <+1% <+1% <+1%	>99% >99% >99% >99%	CO and HC: zero to 90% depending on system of regeneration	€2300 (small system) €7000 (large system)	Cleaning costs: Trucks - €350/yr Buses - €700/yr RCVs - €1400/yr Up to 1% increase in fuel cost	May increase exhaust back pressure outside of manufacturers limits prior to regeneration.
EGR	All heavy-duty	Euro 2: 7 -10 yrs Euro 3: <7 yrs	Up to -50% Up to -50%	Risk of increase. Likely to need mitigation by DOC/DPF	Zero Zero	+2% +2%	Risk of increase		Cost for large veicle: €14000 to €16000	Up to 2% increase in fuel cost	Fuel consumption increase, potential accelerated engine wear. Mitigation of increased PM by DOC or DPF
SCR	All heavy-duty	Euro 2: 7 -10 yrs Euro 3: <7 yrs	-60 to -80% -60 to -80%	-20 to -30% -20 to -30%	Zero* Zero*	Zero Zero	Risk of increase	HC: typically 70% reduction. CO: up to 20% increase.	Cost for city bus:€10000 €15000 (with DPF)	Cost of Urea estimated at €1-2/100km	Needs urea injection system *Can increase N2O through oxidation of NH3
SCR+DPF	All heavy-duty	Euro 2: 7 -10 yrs Euro 3: <7 yrs	-60 to -80% -60 to -80%	>99% >99%	+10 to 50% +10 to 50%	<+1% <+1%	>99% >99%	CO and HC: typically 90% with <50ppm Sulphur.	€12000 (medium system) €15000 (large system)	Cleaning costs: Trucks - €350/yr Buses - €700/yr RCVs - €1400/yr Up to 1% increase in fuel cost Cost of Urea estimated at €1-2/100km	Needs low sulphur fuel (<50ppm) Needs urea injection system Can increase NO2 through oxidation of NH3
Repower to Euro 4	All heavy-duty	Euro 2: 7 -10 yrs Euro 3: <7 yrs	Zero Up to 50%	Up to 45% Up to 43%	Zero Zero	Up to +20% Zero	Could increase	E2 TO E4: HC: 60%,	€16000 to €24000 Cost needs to be	Maintenance costs expected	Expensive. May not give

			Note; based on real world emission tests.					CO:55% E3 to E4 HC: 30%, CO: 25%	compared with like for like replacement cost	to reduce. Fuel cost could increase up to 20%	reductions in solid particles Real world emissions benefits do not follow Euro standards
Ethanol	All heavy-duty	Euro 3: <7 yrs	Meets Euro 4	Meets Euro 4		60% increase due to lower energy density	Could increase	Meets Euro 4	Additional cost can be in region of €10000	Maintenance cost could be +50%	Dedicated engine
DWE	All heavy-duty	Pre-Euro: >14 yrs Euro 1: 10 -14 yrs Euro 2: 7 -10 yrs Euro 3: <7 yrs	-15% But variation in results from tests noted.	-50% to -60% But variation in results from tests noted.	Zero unless used with DOC (see comments ref. DOC)	10% increase	Could increase	Wide variation of results but CO and HCcould increase up to 35%		Fuel cost could increase by 10%. However depend upon tax regime.	Emission benefits appear to be influenced by engine technology level and duty cycle
Dual fuel diesel/natural gas/biogas	All heavy duty, but primarily long haul trucks	Euro 3: <7 yrs	Meets Euro 4	Meets Euro 4	Zero	20% lower	Likely to be higher than diesel with DPF	HC: 80%, CO: 80%	€22000 to €25000	Payback possible in 2 years	Reduced payload, slightly increased maintenance costs. Catalyst required for CH4 management