Defra

Study to Investigate the Feasibility of Developing a Certification Scheme for Technology Retrofitted to HDVs to Abate NOx Emissions

Final Report

AMEC Environment & Infrastructure UK Limited

November 2011

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AMEC Environment & Infrastructure
UK Limited

November 2011

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Executive Summary

Project Context

The Government is interested in examining the extent to which a certification scheme for technology retrofitted to heavy duty vehicles (HDVs – buses and trucks) to abate emissions of oxides of nitrogen (NO_X) could contribute to improved air quality and increased compliance with the European Union ambient air limit value for nitrogen dioxide (NO_2), and the practical implications of such a scheme.

This report summarises the evidence gathered on this topic from a detailed review of the available literature and feedback from consultation with a wide range of stakeholders both before and after a stakeholder workshop held on 20th May 2011. An earlier version of the report was also published by Defra for technical consultation on 21st July 2011 and stakeholder feedback has been taken into account in this final report. The report is intended to present Defra and DfT with some of the necessary evidence to help inform any decisions about establishing a national certification scheme.

This report covers the following three broad subject areas:

i. Emission standards and abatement techniques, which is split into: the options for emission standards available for a national certification scheme; the technologies available for retrofitting to HDVs; viability and operational issues for retrofitting de-NO_X equipment to HDVs; and the capacity of the industry to provide the services (Section 2);

ii. Administering a national certification scheme (Section 3); and

iii. Options available for enforcement of any future Low Emission Zones, other traffic management schemes or incentive schemes such as the Reduced Pollution Certificate (RPC) that could make use of a national certification scheme (Section 4).

Emission Standards and Abatement Techniques

The benefits of a scheme such as this essentially come from bringing forward emissions reductions that would happen naturally over time as the fleet is renewed with cleaner vehicles. If a certification scheme were to be established, earlier implementation and wider applicability would lead to greater benefits in terms of emission reductions. At the same time, the *ongoing* benefits from a scheme diminish over time as the fleet turns over[1].

[1] It is worth noting that when faced with achieving compliance with local traffic management schemes such as LEZs, operators will most likely need to decide between retrofitting an existing vehicle, purchasing a newer second-hand vehicle or purchasing

Where preferences have been stated, most stakeholders have indicated support for the scope of application of a scheme to be for all heavy duty vehicles, and that implementation should be as early as is practicable.

A certification scheme would most likely need to certify de-NO_X equipment according to achieved percentage mass emission reductions of NO_X and NO_2 – with separate quantitative requirements for nitrous oxide (N_2O) and ammonia (NH_3) emissions – from which equivalency to the emission levels set in Euro standards could be inferred. A certification scheme would also need to ensure effectiveness of retrofitted equipment over additional duty cycles as compared to the test cycles used in type approval.

A scheme incorporating certification to Euro V emission standards is potentially more ambitious than a scheme only certifying to Euro IV[2]. However, concerns exist for allowing multiple emission standards due to possible complexity for operators, as well as it being technically difficult to retrofit de-NO_X equipment or adjust existing de-NO_X equipment on Euro IV vehicles to comply with a Euro V standard. Further details are provided in Section 2.2.

Most stakeholders have indicated that a potential certification scheme could be set up as a framework to provide sufficient flexibility for local authorities to be able to introduce local traffic management schemes tailored to the local situation. Local situations will likely vary in their requirements to address: pollution from particular vehicle types (e.g. buses versus HGVs); varying local air quality; and particular pollutants (e.g. NO_2 or particulate matter, PM). As a number of manufacturers produce devices that jointly abate NO_X and PM emissions, certification of devices for both pollutants could therefore be beneficial.

Retrofit Technologies Available for Compliance

A review of technologies that can be retrofitted to HDVs to abate NO_X emissions has considered selective catalytic reduction (SCR), exhaust gas recirculation (EGR) and lean NO_X traps (LNTs). EGR and LNT have been discounted as potentially viable solutions due to technical constraints/concerns and lack of evidence of successful retrofitting to HDVs. SCR appears to be able to achieve NO_X emission reductions exceeding 70% based on experience to date in the retrofitting of SCR to buses (and exceeding 80% in cases except heavy traffic). There is uncertainty in the NO_X emission reduction potential for other HDVs, although experience with one HGV demonstrated >70% NO_X reduction. Some stakeholders have suggested that the identified costs of SCR retrofit equipment may well exceed the projected residual values of pre-Euro IV vehicles that are being considered for

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a new vehicle. From 2013, new vehicles purchased will be of a Euro VI standard, which has an 80% lower NO_X limit value than Euro V, as well as being subject to a new test cycle and off-cycle emission requirements.

[2] Note that Euro V sets out requirements for new vehicles beyond just emission standards. For example, for new vehicles Euro V includes monitoring requirements for SCR units and torque limitations in the event of NO_X threshold levels being exceeded. Based on the stakeholder views gathered to date, it is assumed that a potential retrofit certification scheme would refer to the emission standards part of the Euro standards.

retrofit with a possible implementation date of 2015. This implies that the number of operators that may choose to retrofit vehicles to comply with an LEZ may be lower than those which choose to purchase new or newer vehicles.

SCR can be combined in series with a particulate filter or regenerative trap ('SCR+DPF') to jointly abate emissions of PM, NO_X and other pollutants such as hydrocarbons and carbon monoxide. SCR can lead to increased emissions of some unregulated air pollutants and greenhouse gases, but control measures exist to address these (at additional cost). Further work by industry should help answer the question of whether NO_X reductions greater than 70% could be specified whilst also retaining NO_2 emission reductions at specified levels and acceptable NH_3 concentrations and N_2O emissions. There is significant experience of retrofitting SCR or SCR+DPF devices to buses but a gap in experience for trucks. Trials and pilot schemes in this area, led by industry, could help to address this gap.

Viability issues and operational difficulties

Recent research in the Netherlands and the UK has highlighted concerns that real-world emissions from new HDVs fitted with SCR operating in urban environments are higher than legislative emission standards. For retrofitting SCR this concern appears to be solvable because it is technically feasible to tune SCR systems for specific drive cycles (rather than just to meet limit values during legally required test cycles), including HGVs in urban conditions. It also appears to be possible to calibrate SCR systems for specific NO_2 emission reductions. Calibrated retrofitted systems are not expected to have higher urea consumption rates than correctly functioning SCR fitted on new vehicles operating on the same duty cycle. However, higher urea consumption rates (and thus increased operating costs) may be realised compared to under-performing SCR units fitted on new vehicles operating on urban cycles that are not meeting the required NO_X reduction. Other technical issues identified concerning SCR retrofits include space constraints, particularly on HGVs. Abatement suppliers are confident that they can solve this problem through compact devices or through resolution on a model by model basis. Some consideration of interaction of SCR systems with existing DPFs may be necessary (but not always), but a solution of replacing a DPF with a SCR+DPF device exists, but which comes at a slightly higher cost.

Potential capacity of the retrofitting industry

Up-scaling production for an increased retrofit market is not likely to cause difficulties for the abatement technology manufacturers, as most components are standardised and already manufactured in significantly larger quantities for Original Equipment Manufacturers (OEMs). Design options of a certification scheme that spread demand would be beneficial. The potential timescales for the supply industry to meet demand do not appear to constrain the minimum time requirements around scheme introduction. Fitting of the equipment had been identified as a potential bottleneck for the scheme. In many cases, primarily where captive fleets are concerned, the suppliers themselves expect to undertake the fitting. For smaller fleets including single vehicle retrofits the fitting may be undertaken by a truck dealership following appropriate training from the suppliers. Most stakeholder views gathered indicate that it should not be necessary to establish a fitter certification system because the burden of responsibility for correct fitting lies with the equipment suppliers.

Administering a national certification scheme

The processes that are in place for the operation of the London LEZ (and the RPC) appear to have been largely successful. For consistency, cost-effectiveness and ease of application it is suggested that if a national scheme were taken forward it could be based around this existing design in terms of key roles, responsibilities and databases/IT systems. This is described in detail in Section 3. However, it has not been possible within the scope and timescales of this study to develop a robust estimate of the costs associated with setting up and administering a national certification scheme.

In addition to the databases and systems that would need to be established, an effective publicity campaign is considered to be critical in making relevant stakeholders aware of the scheme and how they can select an approved device and gain certification (in particular, if being applied as part of an LEZ). Early engagement with stakeholders is considered a priority.

In terms of cost recovery, the main option appears to be a fee-based system whereby the certification bodies involved in the process charge to certify devices/suppliers and retrofitted vehicles. However it is likely that income generated from fees may not cover all of the initial set-up costs.

Enforcement options

The enforcement of the use of retrofitted de-NO_X equipment to meet particular emission standards is more difficult than that for PM abatement equipment. This is because PM abatement equipment is considered to reliably continue to abate PM once fitted, whereas de-NO_X equipment – SCR – requires the vehicle operator to regularly top-up with a consumable reagent in order for the device to function correctly.

The annual vehicle roadworthiness inspection process is considered distinct from the options available to local authorities to enforce in-use compliance of vehicles operating within defined traffic management schemes such as LEZs. Annual roadworthiness inspection is unable to check whether a vehicle has complied with a particular LEZ without geolocation of recorded NO_X emission reductions. A number of options for enforcement of schemes such as LEZs have been investigated, some of which attempt to address the concern over in-use compliance for vehicles fitted with SCR. Local authorities will wish to ensure that emission reductions targeted by an LEZ are achieved in practice, but high levels of assurance are only likely to be achieved through expensive and highly specified technical solutions which would have data privacy concerns.

Enforcement options discussed in the report include windscreen sticker-based manual enforcement, automatic number plate recognition systems (both roadside and mobile), remote sensing of vehicle exhausts, and various in-situ monitoring options including the transmission of real-time NO_X reduction data. The final choice (or combination of choices) for a particular LEZ would depend on a number of factors including the accuracy of the enforcement option, the level of compliance, funding available and location specific variables e.g. number of access points to a particular LEZ.

Stakeholders – including local authorities – have given support to 'light touch' enforcement options such as the inclusion of driver aid warning lights, and the possibility for the annual certification to be used (through interrogation of stored data) to determine if the vehicle's retrofitted equipment has been correctly functioning during a set period.

Key Evidence Gaps, Uncertainties and Further Work

A series of outstanding evidence gaps, uncertainties and options for further work have been identified and are described in Section 5.2.

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Contents

1. Introduction

1.1 This Report

The Government is interested in examining the extent to which a certification scheme for technology retrofitted to heavy duty vehicles (HDVs – buses, coaches and trucks) to abate emissions of oxides of nitrogen (NO_X) could contribute to improved air quality and increased compliance with the European Union ambient air limit value for nitrogen dioxide (NO_2), and the practical implications of such a scheme.

AMEC (formally known as Entec) was contracted to investigate the development of such a scheme. This final report provides a summary of the evidence gathered as part of this study against a range of topics including the level at which any standards could be set, the technologies available for abatement and practical aspects related to the way in which any framework could be established and applied. This is intended to present Defra and DfT with the necessary evidence to help inform any decisions about establishing a national certification scheme.

The findings in this report are based on a detailed review of the available literature, feedback from consultation with a wide range of stakeholders during the study as well as discussions with stakeholders at a workshop held on 20th May 2011 and subsequent workshop feedback. Additional stakeholder feedback received in response to an earlier draft of this report published on 21st July 2011 has been taken into account in this final report.

1.2 Project Context

1.2.1 Background

Air quality

Action to manage and improve air quality is largely driven by European Union legislation. The 2008 Ambient Air Quality Directive (2008/50/EC, 'the Directive') sets legally binding limits for concentrations in ambient air of major air pollutants ('limit values') that impact on public health, including particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2). The Directive was transposed in England through the Air Quality Standards Regulations 2010. Equivalent regulations exist in Scotland, Wales and Northern Ireland. This superseded – and combined – the existing Air Quality Framework Directive and three of the four Daughter Directives.

Where compliance with any of the air quality limit values is not achieved, the UK is required to produce air quality action plans detailing the measures that will achieve compliance, and submit those plans to the European Commission. The new Directive introduced provisions for additional time to meet the existing limit values, which the UK is seeking to use for PM_{10} and NO_2.[3] Meeting the NO_2 limit values close to roadsides in London and other

[3] The European Commission has recently announced (March 2011) that it has accepted the UK's time extension notification to allow additional time for meeting the PM_{10} limits (until June 2011).

major cities even by an extended deadline of 2015 is considered to be particularly challenging given the largest source of this pollutant is road transport.

The UK intends to submit a time extension notification to the European Commission by September 2011 outlining the actions being taken at a national and local level to reduce emissions of NO_2 and to achieve the NO_2 limit value within the extended timescales. The time extension notification is currently being finalised and is expected to be consulted upon in June 2011.

Low Emission Zones (LEZs)

A number of towns and cities in the European Union have implemented LEZs with the primary aim of achieving compliance with air quality limit values; to date these LEZs have so far focused almost exclusively on PM rather than NO_X or NO_2. LEZs are geographically defined areas where the most polluting vehicles are restricted, deterred or discouraged from access and use. Most LEZs set a minimum standard that vehicles wanting to access the zone must meet, generally based around the EU mandatory emissions standards for new vehicles ('Euro standards'). Some also allow access to older vehicles that have been deemed to partially meet the standards by retrofitting pollution abatement equipment.

The Government is investigating the feasibility and technical issues surrounding introducing a national framework for LEZs. Within this research they are interested in examining the extent to which a certification scheme for technology retrofitted to HDVs to abate emissions of NO_X could contribute to such a framework by ensuring transparency and consistency of application. A national certification framework for de-NOx abatement equipment could be used to facilitate the introduction of further local transport control schemes such as LEZs. Transport for London (TfL) set up a similar scheme for technology to reduce PM_{10} emissions as part of the London LEZ.

1.2.2 Aims and Objectives

The objective of the study was to summarise existing evidence on the practicality of NO_X retrofit and certification to help clarify key evidence gaps and determine the next steps in coming to a decision about whether or not to implement such a scheme. The main areas of research that Defra and DfT are interested in are:

- Requirements for emissions standards for pollutant abatement technology;
- Retrofitting compliance issues for vehicle operators;
- Administration of a national certification scheme;
- Options for enforcing the standards; and
- The capacity of the retrofitting industry to provide the services.

This work has been steered by Defra and DfT with support from other stakeholders including TfL, the GLA and the Environmental Industries Commission (EIC).

1.3 Structure of this Report

Section 2 of this report sets out the available options for emission standards, the technologies available for retrofitting and the associated technical and/or operational difficulties associated with these technologies. It also includes an overview of investigations into whether the retrofitting industry has the capacity to meet potential demand of a scheme.

Section 3 presents the administrative arrangements that would need to be made to support such a national certification scheme. Related to these are the possible options available for enforcement of any future Low Emission Zones or other traffic management schemes that made use of such a national certification scheme; these are described in **Section 4**.

Section 5 sets out the conclusions of the evidence gathered during the study and remaining evidence gaps.

2. Emission Standards and Abatement Options

2.1 Introduction

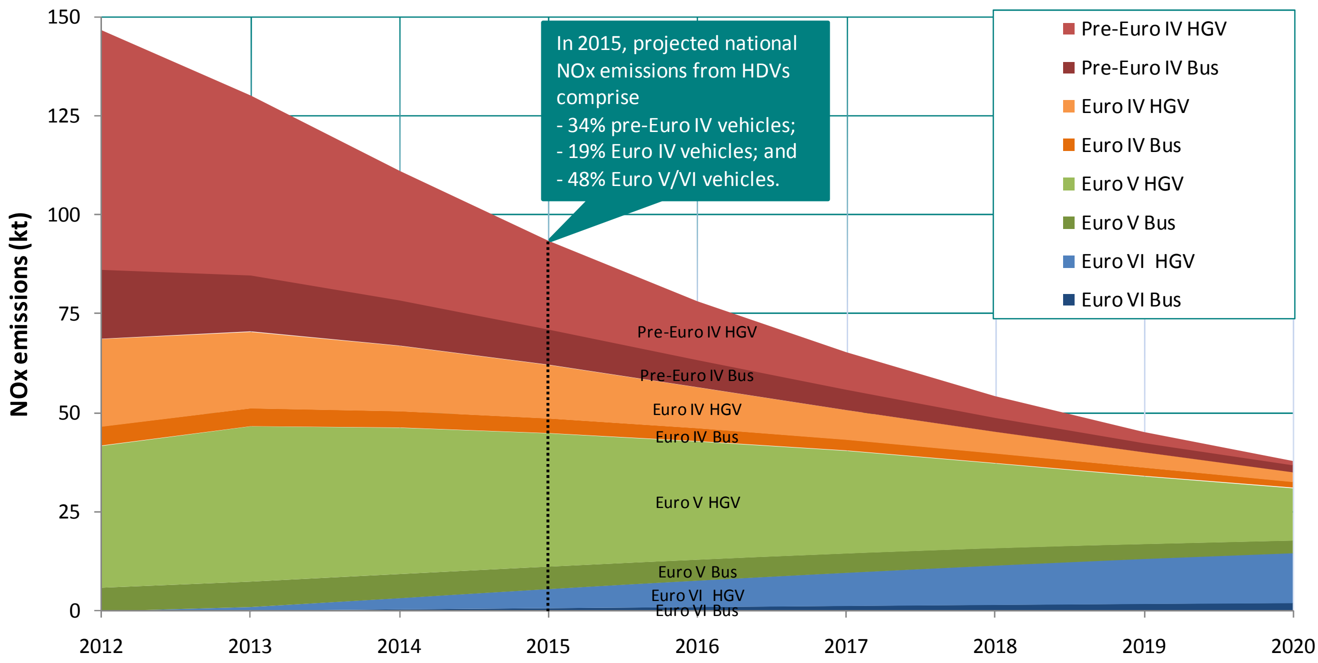
This chapter summarises the evidence gathered during this study on the options available for developing and setting emission standards for a national certification scheme, what technologies are available to be retrofitted to abate NO_X emissions and what technical challenges exist for retrofitting these technologies to HDVs. There is also a discussion on the potential of the retrofitting industry to meet the potential demand that could be introduced by a national framework for LEZs. The research questions that have helped to shape this section are included in Appendix A.

2.2 Options for Emission Standards

2.2.1 Context: UK Emissions Baseline from HDVs

In order to provide context to scoping the options for emission standards, Figure 2.1 below shows the projected national NO_X emissions from HDVs from 2012 to 2020, disaggregated by Euro standard and vehicle type (source: National Atmospheric Emissions Inventory, NAEI). The plot shows national level data rather than for urban or city areas (for which the split between buses and HGVs would be different), but can be used at least as an indicator for identifying the potentially optimal timescales for introducing any standard. The plot shows that a scheme aimed at reducing NO_X emissions from pre-Euro IV buses and HGVs in 2015 targets approximately 34% of total NO_X emissions from HDVs. By contrast, a scheme aimed at reducing NO_X emissions from pre-Euro V buses and HGVs in 2014 would target 58% of total NO_X emissions from HDVs. In 2013, this rises to 46% and 64% of NOx emissions from pre-Euro IV and pre-Euro V HDVs, respectively. However, it is important to recognise that the projections plotted in Figure 2.1 assume emission factors consistent with meeting the emission standards, and therefore do not reflect the fact that real-world emissions may be higher than expected for some vehicle types, as discussed in Section 2.4.2. It is also important to note that many Euro IV HDVs are already fitted with SCR equipment.

Figure 2.1 NAEI (base 2009) NO_X Emission Projections for HDVs



The benefits of a scheme such as this essentially come from bringing forward emissions reductions that would happen naturally over time as the fleet is renewed with cleaner vehicles. Figure 2.1 reinforces the emphasis that the earlier a scheme is brought in, and the wider its scope of application, the earlier the potential benefits that could be derived. The continued benefits from the potential implementation of a scheme diminish over time as the fleet is renewed naturally. This is of course linked with the possible compliance routes that operators could choose when needing to comply with a potential scheme: operators will either retrofit their existing vehicles or purchase new vehicles. The decision to retrofit abatement equipment to an existing vehicle may represent, at least in part, a decision by the operator to extend the life of the vehicle due to the capital investment made and consequently delay the purchase of a new vehicle (which from 2014[4] would meet Euro VI standard) or a newer second hand vehicle.

2.2.2 Developing UK Standards versus Adopting Other Standards

One element the UK Government was keen to understand was the availability and applicability of standards developed outside of the UK for use in a national certification scheme. The adoption of standards developed outside the UK may be beneficial in terms of having standards harmonised with neighbouring countries, which is important for operators of vehicles that visit multiple countries, as well as for the EU. However, it is also important for the UK Government to have certainty in the timescales for adopting standards as well as the level at which they are set.

[4] Euro VI comes into force for new type approvals from 31 December 2012 and for new registrations from 31 December 2013.

The UNECE's Inland Transport Committee, through the World Forum for Harmonization of Vehicle Regulations and its Working Party on Pollution and Energy (UNECE GRPE)[5], is developing a draft Regulation on uniform requirements for retrofit emission control devices for HDVs. This draft Regulation aims to provide a worldwide harmonised method for the evaluation, approval and classification of retrofit emission control systems for NO_X and/or PM and particle number (PN), and for the determination of the levels of emissions from such vehicles. The Regulation would only have legal standing if the UK referred to it as a standard in a legal document.

The draft of the UNECE Regulation (as at August 2011) classifies retrofit NO_X emission control systems into categories according to the percentage NO_X emission reductions achieved from the engine-out emissions and additionally by whether or not the control system also reduces PM emissions. Stakeholders have indicated that although there was interest in completing the standard in 2011, current expectation is that it could be delivered by June 2012. However there is no guarantee of this, particularly because discussions could break down if members cannot agree to draft texts. Other stakeholders have indicated that the draft Regulation may not be finalised until spring 2013. Implementing legislation that would enact any UNECE Regulation would be unlikely to take effect until 2014 at the earliest.

Given that the UNECE Regulation is still being developed and there are uncertainties over timescales, abatement equipment suppliers have indicated that it could be advantageous for the UK to develop its own certification scheme and in parallel to take a lead in the UNECE discussions for finalising the Regulation using the UK scheme to steer negotiations of the Regulation. However, representatives from the DfT have indicated that they do not expect it to be feasible to develop a UK scheme early enough in order to influence the UNECE discussions.

Discussions on this topic at the May 2011 stakeholder workshop indicated that if the UK wished to pursue the development of a national certification scheme then it could be best to develop its own standards with UNECE assistance. This is considered likely by stakeholders because the UNECE working group appear keen to help the UK develop a standard, which may in turn shape the UNECE Regulation.

If the UK were to develop its own standards, consideration would need to be given to the potential timescales for implementation due to the need to provide sufficient lead-in times for industry to supply equipment and operators to make choices on whether or not to retrofit their vehicles. The timeframes are discussed in Section 2.2.3 below.

2.2.3 Potential Timelines

The timescales over which emission standards could be set as part of a national certification framework would need to both allow suppliers of abatement equipment sufficient time to develop devices and get them certified to a pre-defined standard, as well as to allow sufficient time for operators to fit abatement equipment and get their vehicles certified in advance of any standards being applied e.g. as part of an LEZ.

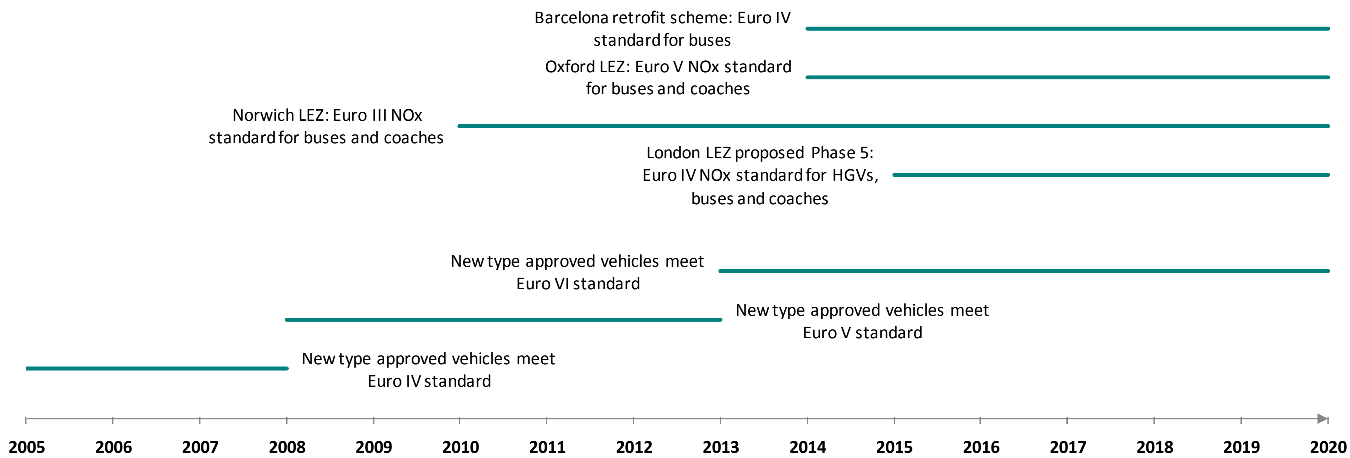
The first of these two time demands has been suggested by stakeholders to be at least one year to allow suppliers to become certified and to produce certified devices. The second, suggested by TfL based on their experience with the

[5] http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/rec04.html

London LEZ, is recommended to be at least one year (i.e. two years in total with the first) to allow operators time to understand the certification scheme requirements and to make decisions on the optimal solution for their fleets. The Society of Motor Manufacturers and Traders (SMMT) has suggested that the total of these two time demands is at least three years.

Figure 2.2 below plots the timescales for the Euro standards IV, V and VI that apply for new vehicles alongside a selection of UK and non-UK schemes and potential schemes targeted at NO_X that require certain vehicles to meet defined Euro standards.

Figure 2.2 Timeline of Euro standards coming into force and selected schemes



Note: the Euro standard timelines included above are for new vehicle type approvals. The equivalent dates for new vehicle registrations are one year later.

From the above figure it is evident that some schemes (proposed or not) apply to certain HDV types and not others, for example to buses but not goods vehicles. The reasons why this strategy may be pursued in a particular urban area are likely to be specific to that area. For example, the Oxford scheme is aimed at reducing emissions from city centre buses because these are the primary NO_X and NO_2 pollution sources from HDVs in the city centre. In addition, the scope of a scheme may be limited to certain vehicle types for ease of application e.g. buses may be operated by a small number of companies so are perhaps easier to include. A certification scheme could be flexible to allow local authorities to apply standards separately to HGVs versus buses/coaches. Further support for this strategy is explained in Section 2.3.1. Stakeholders expressed support for this flexibility at the study workshop.

Stakeholders have indicated that it can be easier for haulage truck operators to buy new vehicles than to retrofit, whereas the cost/benefit ratio changes for more special purpose HDVs such as cranes, electrical power units, construction site equipment and cement mixers. For these vehicles, the motivation to retrofit is higher than to replace the vehicle due to the value of the auxiliary equipment on the vehicle. Furthermore, these types of vehicles may well be operating in city centres whereas long-haulage trucks may operate primarily outside of urban areas.

The Freight Transport Association (FTA) provided their initial estimate for the number of HGVs that will be pre-Euro IV in 2015; around 130,000 out of a total parc of 426,000 HGVs, which we have not been able to confirm with them. Without financial incentives to retrofit, the FTA has indicated that the number of vehicles that could be expected to retrofit de-NOx equipment to meet LEZ entry requirements would likely be much lower than this figure.

2.2.4 Overall Design of Emission Standards

An emissions standard can be based on defining emissions or emission reductions in different ways, such as:

i. Absolute quantities, such as grams emitted per kilometre (g/km) or per kilowatt-hour (g/kWh);

ii. Concentrations of pollutants, such as parts per million (ppm) or milligrams per cubic metre (mg/m^3);

iii. Relative reductions in mass of pollutants emitted, expressed as percentages; or

iv. Maximum mass emission percentage increase, or maximum CO_2-equivalent increase (to limit increases in emissions of those pollutants that are not the target of reductions).

Experience from the UNECE GRPE, supported by stakeholders contacted in this study, suggests that **a national certification scheme be based around point iii. of the above list for the pollutants to be addressed**. Although this deviates from the absolute quantities referred to in the Euro standards (g/kWh for HDVs), the certification of individual devices on vehicles is very difficult to achieve in absolute terms that are comparable with Euro standards. Measurements of concentrations of pollutants in exhaust gases are made before and after treatment, yielding values according to points ii. and iii. in the above list. Although for individual vehicles it is possible to convert such values into g/kWh, due to the very high number of combinations of vehicle engines and exhaust treatment devices, converting values to g/kWh is not a viable option.

Nonetheless, it is also possible to associate defined percentage emission reductions as being 'equivalent' to bringing a vehicle registered as Euro X standard to the emission limits of Euro Y standard. This approach is already adopted for many LEZs across Europe, including the London LEZ. Table 2.1 sets out these percentage reductions for NO_X emissions as equivalent to meeting Euro standards. Stakeholders have indicated that it is important to focus efforts on maximising the emission reductions from the devices, not on which Euro standard equivalent LEZs should focus.

It is important to note that Euro V sets out requirements for new vehicles beyond just emission standards. For example, for new vehicles Euro V includes monitoring requirements for SCR units and torque limitations in the event that NO_X threshold levels are exceeded. Based on stakeholder views gathered during this study, it is assumed that a potential retrofit certification scheme would only refer to the emission standards component of the Euro standards, and not any additional requirements. Stakeholders at the workshop indicated that classification of devices according to inferred equivalence to Euro standards would require text such as "*shall be recognised as equivalent to*" in a formal certification document.

Table 2.1 Reduction in NO_X Emission Factors Among Euro Standards

Base vehicle standard	Year of implementation	Estimated proportion of fleet (% of km driven) in 2015 (Note 2)	Emission factor (g NO_X/kWh)	Reduction equivalent (%) to meeting resulting standard			
				Euro III	Euro IV	Euro V	Euro VI
pre-Euro	1988	0%	14.4	65.3%	75.7%	86.1%	97.2%
Euro I	1992	0%	8.0	37.5%	56.3%	75.0%	95.0%
Euro II	1996/8	1%	7.0	28.6%	50.0%	71.4%	94.3%
Euro III	2000/1	12%	5.0	-	30.0%	60.0%	92.0%
Euro IV	2005/6	11%	3.5	-	-	42.9%	88.6%
Euro V (Note 1)	2008/9	45%	2.0	-	-	-	80.0%
Euro VI	2013/14	31%	0.4	-	-	-	-

Note 1: The Enhanced Environmentally friendly Vehicle (EEV) standard also has a NO_X emission level of 2.0 g/kWh.
Note 2: As included in the NAEI road transport emission projections (Pers. Comm., AEA, January 2011).

The table above suggests that a certification scheme aimed at requiring Euro IV standard would necessitate NO_X reductions below 70% from Euro I, II and III standards, but greater than 70% NO_X reduction by pre-Euro I vehicles. For a scheme requiring vehicles to meet Euro V standard (which is supported by some stakeholders), NO_X reductions of less than 70% would be necessary for Euro III and IV vehicles, but greater than 70% NO_X reductions for pre-Euro I (86%), Euro I (75%) and Euro II (71%) vehicles. The table also indicates the estimated fleet composition as a proportion of vehicle kilometers in 2015, which shows that pre-Euro I, Euro I and Euro II vehicles are expected to make up 1% of distance traveled (yet potentially 3.5% of total HDV NO_X emissions – see Figure 2.1). In 2015, Euro II vehicles will be at least 15 years old.

By 2015, Euro III and older vehicles will be at least nine or ten years old. Stakeholders have indicated that the residual values of some of these vehicles in 2015 may be lower than the foreseen retrofit costs of de-NO_X equipment suggested in Section 2.3. For example, the FTA has estimated that the residual value of a 9 year old 17t rigid truck in 2015 would be around £2,500[6] which may lead vehicle operators to decide that the retrofitting of de-NO_X equipment to be uneconomic. However, many specialist vehicles, and some buses and coaches, may be worth considerably more than this such that operators may want the option of retrofitting to comply.

A national framework could allow certification to multiple emission standards, giving the choice to local authorities as to which level of Euro standard equivalent should be applied in a local traffic control measure, perhaps linked to the scale of any air quality problems in that area. This would be implemented by approved device lists stating the equivalency of Euro standard achieved for Euro standard being retrofitted. If the framework permitted multiple emission standards, then it could result in urban areas across the UK having traffic control measures with different vehicle restriction requirements making compliance for operators more complex (although it could also be

[6] Personal Communication from FTA, 27 May 2011. Assuming 5% of original purchase price of £50,000 in 2006.

envisaged that fees for LEZ access are graduated based on emission levels, or that subsidy be provided to meet more stringent emission levels). At the same time, without the introduction of a national framework, the LEZs already proposed in the UK as set out in Figure 2.2 appear likely to adopt different emission standards that are targeted at local bus/coach fleets. Stakeholders have not specified any technical barriers with respect to allowing the certification scheme to certify vehicles to different Euro standards. One stakeholder has indicated that if both NO_X and PM emissions are to be regulated within a local traffic control measure, a single Euro standard equivalent should be adopted rather than a hybrid that combines for example one Euro standard for PM and another Euro standard for NO_X. It is unclear whether other stakeholders share this view.

If a standard of Euro V for all vehicles were set then vehicles which meet the Euro IV standard and may already have SCR fitted could be affected. For such vehicles, stakeholders suggest that it is not possible to adjust the existing SCR system to reduce NO_X to a greater degree, and for those vehicles without SCR it may not be practical or cost-effective to retrofit. An alternative to retrofitting abatement equipment to Euro IV vehicles would be to require that retrofitting of pre-Euro IV vehicles is undertaken up to a standard equivalent to Euro V, but that Euro IV compliant vehicles would be permitted without any retrofitting in recognition of the smaller reduction required to go from Euro IV to Euro V standard. Such a split requirement could have equality implications; indeed some stakeholders consider that both new and retrofitted vehicles should have to meet the same standards (e.g. meeting the emission levels of Euro V). These technical and political aspects remain as evidence gaps.

For a discussion of designing standards for specifically controlling emissions of NO_2, NH_3 and N_2O, see Section 2.4.

2.2.5 Testing of Vehicles Retrofitted with Abatement Equipment

Vehicles retrofitted with de-NO_X equipment need to be tested to ensure the equipment is functioning and to quantify the emission reductions being achieved. For new vehicles, testing is undertaken on engine dynamometers according to standardised test duty cycles as specified in European legislation. For retrofitted vehicles, testing can be undertaken according to the same cycles, but because no legal requirements are in place, other testing could be undertaken. The possibility exists to test not just the engine (as for new vehicles) but the whole vehicle on a chassis dynamometer under 'real-world' test cycles such as FIGE or Braunschweig City cycle. The FIGE cycle is the vehicle version of the engine cycle used for Euro IV and V certification. Although it is derived from real world data, stakeholders have indicated that it hasn't been effective in controlling NO_X emissions in urban operating conditions. In response to concerns over in-use compliance, the Euro VI standard has further developed requirements for testing.

Stakeholders have indicated support for chassis- rather than engine-based testing, and that a scheme should specify the test cycle including the urban cycle. At the workshop, stakeholders expressed support for the adoption of Euro VI test cycle requirements for a certification scheme. Testing is most likely to be undertaken for the equipment certification phase described in Section 3.2.

2.3 Technologies Available for Compliance

2.3.1 SCR

The majority of de-NOx systems retrofitted to date are selective catalytic reduction (SCR) systems. These can be part of a combined NO_x and PM abatement system that incorporate a particulate filter or regenerative trap in series with SCR (hereinafter referred to as SCR+DPF). Consultation with suppliers has indicated that suppliers are focussing their efforts on developing combined SCR+DPF solutions due to perceived market direction.

SCR reduces NO_x by injecting urea solution into the exhaust, where it dissociates to produce ammonia which reacts with the NO_x in the presence of the catalyst to produce water and nitrogen. SCR thus requires the use of an additional on-board tank to store the reagent, which the user is required to top-up in order for NO_X reductions to occur. SCR is an end-of-pipe measure and can be retrofitted to Euro I onwards HDVs, although the cost of retrofitting to pre-Euro II vehicles may not be justifiable due to the limited remaining life of the vehicle. No technical concerns have been identified with retrofitting SCR to Euro I or II vehicles in terms of dirty exhausts.

SCR or SCR+DPF systems can yield high NO_X conversion efficiencies, but it is recognised that there is a trade-off between reducing NO_X emissions and addressing other pollutants of concern such as NO_2, N_2O and NH_3. It is worth noting however that SCR systems have less of a trade-off with NO_2 than SCR+DPF systems. Section 2.4.1 discusses impacts on other pollutants in more detail. Abatement equipment suppliers offer SCR based solutions with NO_X reductions typically around 70% and some at 80% for buses. Data received from one abatement supplier indicates SCR+DPF devices retrofitted to Euro II/III buses achieving NO_X emission reductions greater than 80% in city centre and suburban routes, but slightly lower (greater than 70%) during operation in heavy traffic on an inter-urban route. It has been suggested by manufacturers that achieving NO_X conversions of greater than 70% can result in potentially significant cross-media impacts on N_2O, NO_2 and NH_3 emissions.

NO_X reductions of 70% should theoretically allow Euro I+ engines to meet the Euro IV standard and Euro III+ to meet the Euro V standard. If products offered 80% NO_X reductions, pre-Euro engines could theoretically meet Euro IV standard and Euro I+ would meet Euro V/EEV. Experience of abatement suppliers in practice[7] suggests that SCR retrofits to buses have typically been used to bring Euro II and Euro III buses to a Euro V standard, for example in the Barcelona scheme (see Box 1), for which the former would require a 71% NO_X reduction.

[7] Personal communications with Proventia and Eminox.

Box 1	Case study: Barcelona scheme retrofitting de-NO_X equipment to city buses

Following a Catalonian Decree, the Transports Metropolitans de Barcelona initiated a retrofit scheme in 2010 for the city buses in order to reduce NO_X and PM emissions and improve local air quality. In the scheme, approximately 400 buses, which were a mixture of Euro II and III standards, were retrofitted with combined SCR+DPF systems, which reduced their NO_X emission levels to those equivalent to Euro V (the decree required a minimum standard of Euro IV). Testing to verify NO_X emission levels following retrofits was undertaken independently by local test stations on the ETC and ESC test cycles. The de-NO_X equipment was additionally calibrated for duty cycles specific to bus routes in Barcelona.

Two suppliers provided the abatement equipment. In order to avoid loss of passenger capacity on board the buses, and to fit the equipment into the tight space envelope available on the vehicles, one supplier developed a compact version of an existing product at a zero cost premium (the supplier absorbed this cost as R&D), with no trade-offs on performance or urea tank size capacity.

To date, SCR has only been retrofitted in significant numbers to buses in the UK and Europe; experience of retrofitting to HGVs is limited in Europe to one supplier. However there have been a few hundred retrofits to trucks in the USA. Results of engine testing of SCR+DPF systems retrofitted to heavy-duty diesel engines in the USA show NO_X reductions in excess of 70% while also achieving at least 90% in PM reduction over the US test cycles HDD FTP and SET[8]. On-board operational NO_X reduction has been measured as high as 84% via the use of NO_X sensors at the engine outlet and the tailpipe.

Manufacturers consulted suggest that although some technical issues have been mentioned for trucks (included in Section 2.4), if demand for retrofitting SCR to HGVs is clear, suppliers should be able to come up with solutions and thus be able to retrofit SCR to UK trucks. Other stakeholders have indicated that the gap in experience of retrofitting to trucks is not as a result of any specific technical restrictions. Instead it has been suggested that the focus on buses has been as a result of public sector fleets responding to local air quality concerns. Although buses and HGVs often use similar engines, and that engines rather than vehicles are certified to meet Euro standards, the two main differences between buses and HGVs which affect the performance of retrofitted SCR are (i) buses have smaller engines relative to their weight than HGVs (i.e. different on load factors), and (ii) buses do more stop-start driving than HGVs (i.e. different duty cycles).

Manufacturers suggested that combined SCR+DPF systems for HGVs and buses have similar costs. A wide range of capital costs, £4,000-14,000, for SCR and SCR+DPF systems have been provided by manufacturers. Costs of SCR+DPF are typically around 15% to 25% higher than SCR costs. In some cases a reduction of 20-30% could be expected if an increase in demand results in sufficient increase in manufacturing volumes to achieve economies of scale (i.e. from 10s of devices to 1000s of devices). However, it has been suggested that volumes may not increase significantly due to the possibility of operators reorganising their fleets to move vehicles to areas without imposed traffic control measures such as LEZs. Due to the commercial sensitivity of cost/price information further details are not presented here.

The on-going costs from urea consumption (assuming urea consumption at around 5% of diesel consumption and urea solution prices of 50p/litre) for a small HGV covering 50,000 miles per year may be around £400 per annum, whilst a larger (e.g. 24 tonne) HGV covering 100,000 miles/year may be around £1,500 per annum. There is a

[8] Personal communication with Johnson Matthey, June 2011 and results presented on US EPA Verified Diesel Retrofit Technologies (http://epa.gov/cleandiesel/verification/verif-list.htm)

direct relationship between NO_X reduction and urea consumption, such that, for the same NO_X reduction, OEM and retrofitted devices should have the same urea consumption. However, in practice if retrofitted SCR devices reduce NO_X to a greater degree than OEM devices (e.g. in urban areas, see discussion in Section 2.4.2) then urea consumption may be higher.

Fitting duration is expected to be around one man-day with a cost of around £250 per vehicle. For larger fleets this is expected to decrease whereas for single vehicles retrofitted at the owner's premises this could increase.[9] Annual servicing costs are currently around £600 but are expected to fall to £300 to £400 at larger volumes. Operational difficulties for operators are not expected if annual maintenance regimes are adhered to. Furthermore, DfT have indicated that the cost to an operator may be an additional £400 for lost vehicle and driver time (split equally between these two). Stakeholders have suggested that maintenance would be expected to be the same for HGVs as for buses/coaches.

Stakeholders have also suggested that due to the fact that retrofitted SCR based systems are exposed on the vehicles, there is a risk for damage and theft of equipment which operators would need to consider.

2.3.2 EGR

An alternative de-NO_X retrofit measure is exhaust gas recirculation (EGR). EGR systems recirculate a proportion of the exhaust gas in with the air injected into the engine cylinder. This reduces the oxygen content of the gas in the cylinder resulting in lower combustion temperature and therefore less NO_X formation. Retrofitting EGR generally requires extensive engine rebuilds impacting on capacity, turbo chargers and other components (at very high cost).

EGR retrofitting as a NO_X reduction strategy was trialled by TfL on buses some years ago but was not successful. The retrofits that were undertaken resulted in higher fuel consumption, increased PM emissions and a performance reduction, and in some cases failed to meet a target NO_X reduction of 50%.

On this basis, EGR has not been considered further as a retrofit solution in this study.

2.3.3 Other Technologies

Other types of de-NO_X abatement equipment include lean NO_X traps (LNT). However it appears that they are not suitable for retrofit as they need specific engine calibration in that engines need to run at stoichiometric air/fuel ratio periodically to allow for NO_X conversion. No evidence for LNTs applied as retrofit solutions for heavy duty engines has been found, such that these are not considered suitable for retrofits.

The use of fuel borne catalysts may also be an option for NO_X reduction, however insufficient information was available on this measure during the course of this study.

[9] Personal Communication, 20 May 2011.

2.4 Viability Issues and Operational Difficulties

2.4.1 Impacts on Emissions of Non-regulated Pollutants

Without appropriate controls, SCR based systems are known to increase emissions of non-regulated pollutants. Control measures do exist to address these issues, but a ‘system-level’ view is often necessary because trade-offs exist among the pollutants, as introduced in Section 2.3.1. This section addresses each pollutant in turn.

Two of the manufactures consulted indicated that, although there are no significant problems with secondary emissions on their units currently achieving 70-80% NO_x reduction, if the reduction required increases then there may be knock-on impacts on other pollutants. Testing will be performed if and when they develop such systems.

Johnson Matthey and Eminox’s joint retrofit field trial from 2005 to 2007 of an SCR+DPF system to 14 Euro III buses demonstrated that with the technology available then, 69% NO_X conversion was possible with N_2O increase limited to 1% increase in CO_2 equivalent, tailpipe NO_2 limited to 20% of engine-out NO_X and only trace quantities of tailpipe NH_3.[10] It is unclear what absolute NO_2 emission reductions were achieved by this trial. System reliability (in terms of operational time) exceeded 98%.

NO_2 emissions

NO_2 emissions are not regulated by the Euro standards as such; limits are prescribed for NOx instead which includes NO_2. Stakeholders have raised concerns over the possibility that SCR increases the primary-NO_2 percentage share in NO_X emissions in vehicle exhausts. Although SCR units achieve high NO_X reductions overall, it is theoretically possible for SCR units that have not been calibrated to address NO_2 emissions to actually increase tailpipe NO_2 emission levels. It is important to note that the tailpipe NO_2 emission levels following an SCR unit are highly dependent on engine-out NO_2 emission levels, which are themselves variable both among different engines and from single engines over time.

In a SCR+DPF combination, the filter initially increases concentrations of NO_2 before the NO_2 is subsequently removed alongside NO by the injected NH_3 (urea). SCR catalyst reactions are optimal with a 50:50 split between NO and NO_2 emissions. If this 50:50 ratio is used in an SCR unit, there is a theoretical possibility of increasing NO_2 emission levels. For example, if engine-out NO_X emissions are in a typical ratio of 9:1 of NO to NO_2, and an SCR+DPF unit which abates NO_X emissions by 70% is fitted and which is manufactured to operate at the ratio of 50:50 NO to NO_2, then tailpipe NO_2 levels may be 50% higher than engine-out NO_2 concentrations. However, it is important to reiterate that this outcome is considered avoidable if the SCR design and calibration includes a focus on NO_2 emissions. It is also worth noting that from a manufacturing perspective, stakeholders have suggested that space envelope restrictions (discussed in Section 2.4.3) dictate SCR design to a greater extent than optimising catalyst reactions for 50:50 NO/NO_2 mixtures.

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[10] Johnson Matthey and Eminox (2007). Final report on the performance, reliability and durability of a retrofit CRT + SCR system for buses in London. Document number NPD-07-128 1.

Stakeholders agree that SCR can be calibrated to address NO_2 reductions, but that this calibration trades off with NH_3 and N_2O emissions. For example, a 95% NO_2 reduction is possible but with an N_2O trade off. Abatement equipment suppliers indicate that more work is necessary to address NO_2 emissions from SCR based systems, although retrofit solutions are in some places more able to address NO_2 (through calibration) than Original Equipment Manufacturers (OEM). One supplier has indicated that SCR systems are better able to reduce NO_2 specifically than SCR+DPF devices because the DPF devices oxidise a proportion of the engine-out NO to NO_2 which affects the favoured reaction in the unit. Suppliers have indicated that work is in progress on SCR catalysts and system calibration which is focussed on reducing the NO_2 constituent of tailpipe NO_X and results are expected by the end of 2011.

In other areas however, consultation with stakeholders has yielded some conflicting claims. One abatement equipment supplier has indicated that tailpipe NO_2 emissions following SCR systems are low, approximately 5 to 10% of total tailpipe NO_X, and that an SCR unit achieving 70% NO_X reduction can also achieve 70% NO_2 reduction. This latter claim has been refuted by another supplier, but also supported at least as an upper bound for NO_2 emission reduction targets by a third supplier for SCR rather than SCR+DPF solutions.

In spring 2011 TfL invited tenders for a SCR+DPF retrofit trial on 18 London buses. As part of the specification for this invitation to tender, TfL has specified NO_2 emission reductions of the SCR+DPF solutions to exceed 50%. It will be important to follow the outcome of this trial which is expected to begin in the autumn of 2011.

NH_3 emissions

Vehicles without SCR should not emit ammonia (NH_3) whereas SCR systems can lead to emissions of NH_3. As stated earlier, SCR units achieve NO_X reductions by dosing with a urea solution as a reagent. When correctly calibrated, dosing can be undertaken such that 'ammonia slip' – NH_3 emissions – can be minimised to trace levels. This is most easily undertaken through the use of 'closed loop control' in which NO_X sensors both before and after the SCR unit provide a feedback mechanism to adjust the urea dosage in response to variations in engine NO_X emissions. Without such controls (i.e. with dosage at fixed rates) if NO_X emissions from the engine decrease (for example in lower ambient temperatures) then too much urea is injected leading to raised NH_3 emission levels. Closed loop control has an additional benefit of providing the possibility to record real-time abatement efficiencies, as discussed later in Section 3.2.4 and 4.2.

Manufacturers have addressed this for systems using open loop control (i.e. without sensor-based feedback) through the application of an additional NH_3 clean-up catalyst as a safeguard measure, but such catalysts increase N_2O emissions which is undesirable.

Some stakeholders have indicated that NH_3 emission limit of 25ppm could be achievable without a separate NH_3 catalyst. Further to this, for the above-mentioned forthcoming TfL SCR+DPF retrofit bus trial, TfL has specified an NH_3 emission limit for the SCR+DPF solutions of 10ppm, in-line with Euro VI. As for NO_2, it will be important to follow up on the results of this trial towards the end of 2011.

N_2O emissions

N_2O can be produced from imperfect conversion in the reduction catalyst in the SCR unit. Good design and calibration of SCR systems minimises the increase in N_2O emissions. As NO_X emission reduction efficiencies are increased, N_2O emissions typically increase exponentially as urea is injected over a wider temperature window. As stated above, N_2O emissions are also influenced by NH_3 clean-up catalysts.

Stakeholders have indicated support for a limit on N_2O emissions expressed as a function of CO_2 equivalence (CO_2e). A limit of allowing a maximum rise in CO_2e emissions of 1% was adopted in TfL field trails of SCR systems in 2005-2007, and has also been specified for the 2011 TfL field trials of SCR+DPF products. Due to the much greater global warming potential of N_2O compared to CO_2, such a limit of 1% corresponds to a trace quantity of N_2O.

CO_2 emissions and fuel consumption

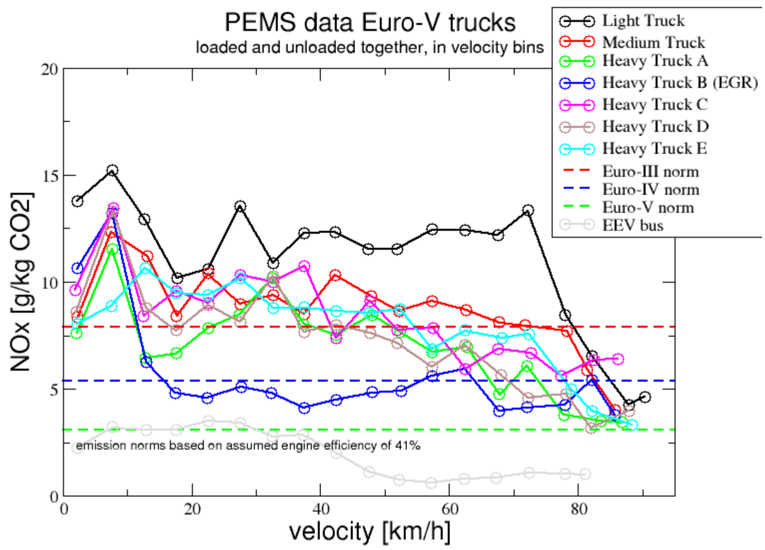
Unlike SCR units on new vehicles, for which engines can be tuned for improved fuel consumption, no such tuning is possible when retrofitting SCR. However, abatement equipment suppliers indicate that, on average across vehicles tested, there is no discernable fuel consumption penalty for SCR. For SCR+DPF systems, which potentially increase backpressure, there can be a small fuel consumption penalty and corresponding CO_2 emissions increase of less than 1%. Suppliers have indicated that it is difficult to isolate fuel consumption impacts specifically to retrofitted de-NOx equipment due to the high number of other factors that affect fuel consumption. The total additional mass of the equipment is around 120kg on average. One stakeholder considers it important to make clear to operators retrofitting abatement equipment to achieve an emission level equivalent to e.g. Euro V standard that the same fuel economy cannot be guaranteed as for an engine specifically designed and certified to meet that Euro standard.

2.4.2 Abatement Efficiency in Urban Drive Cycles

Urban drive cycles are considered most problematic in generating sufficiently high exhaust temperatures for correctly functioning SCR units. Vehicles that do not have sufficiently high operational exhaust temperatures pose the greatest challenge, as insufficient time above the catalyst activation temperature means that the SCR unit will not function or the SCR+DPF will not regenerate (typical requirements are for exhaust gases to exceed 240˚C for at least 30% of time).

In addition, concerns have been raised over the performance of SCR fitted to Euro IV and V vehicles in real-world conditions. Actual NO_X emissions from such modern new vehicles do not appear to be in-line with previous assumptions on NO_X emissions. For example, a TNO study[11] undertook in-situ measurements of Euro V trucks and concluded that under urban conditions, the Euro V trucks consistently showed NO_X emissions of about 3 times higher than previously estimated (this relationship was much weaker at higher speeds), which meant that Euro V NO_X emission limits were being exceeded in urban conditions. Figure 2.3 to the right summarises the data that supported this conclusion in the TNO study.

Figure 2.3 Average Euro V NO_X emissions (per kg CO_2) for different velocities and trucks (Source: TNO, 2009)



More recent work in the UK[12] supports this view with evidence to suggest that SCR is not as effective on HGVs in urban conditions due to low operating temperatures. This work concludes that targeting specific fleets (e.g. urban bus fleets) for retrofitting does have the potential to reduce NO_X emissions, but that it is important in the case of SCR that the technology is matched to specific duty cycles e.g. optimised to deal with lower engine-out temperatures.

Calibrated retrofitted systems are not expected to have higher urea consumption rates than correctly functioning SCR fitted on new vehicles operating on the same duty cycle. However, higher urea consumption rates (and thus increased operating costs) may be realised compared to under-performing SCR units fitted on new vehicles operating on urban cycles when not meeting the required NO_X reduction.[13].

According to some stakeholders, operators report anecdotal evidence of low urea consumption on urban delivery vehicles which support the conclusions of the TNO and UK studies. As such, it has been suggested that a scheme to investigate the recalibration of OEM SCR units on Euro IV and V vehicles to ensure functionality in urban environments would be effective.

[11] TNO (2009). On-road NOx emissions of Euro-V trucks. Report number MON-RPT-033-DTS-2009-03840.

[12] Carslaw, D., Beevers, S. Westmoreland, E. Williams, M. Tate, J. Murrells, T. Stedman, J. Li, Y., Grice, S., Kent, A. and I. Tsagatakis (2011). Trends in NOx and NO2 emissions and ambient measurements in the UK. Version: 3rd March 2011. Draft for Comment.

[13] Personal communication with Eminox.

Trials of bus SCR retrofits in London and Edinburgh have achieved an average of 70% NO_x reduction over the whole bus drive cycle (i.e. which included idling) because in parts NO_x reduction can be over 90%.

Consultation with stakeholders in this study has concluded that it is technically feasible to tune retrofitted SCR systems to optimise performance for the vehicle's normal drive cycle, including HGVs in urban conditions. The tuning of devices is undertaken prior to fitting on the vehicle. There is limited ability to retune the unit via the engine control unit (ECU) after it is fitted (e.g. if the purpose, and drive cycle, of the vehicle changes). In contrast, SCR units fitted to new vehicles are not currently calibrated specifically for urban conditions as the current European test cycle requires NO_X emission reductions over the whole test cycle (which comprises three test environments, including urban), such that the devices are able to meet the average requirement by just tuning NO_X emission reductions according to motorway driving conditions. If an SCR system is tuned to achieve 70% NO_X abatement for an urban drive cycle, it is likely that higher NO_X abatement will then be achieved for motorway driving as during the latter the exhaust gas temperature is sufficiently high for the SCR to operate for a greater proportion of the time in use. For other duty cycles which are not included in the test cycle, no significant effects on the SCR unit are expected because following calibration the unit responds to operating conditions not to urea injection rates. One supplier has indicated that N_2O emission levels required for urban drive cycles can also be met during other drive cycles including motorway driving.

Experience of one abatement supplier retrofitting SCR to a truck led to 58% NO_X reduction of a truck operated on an 'urban bus' duty cycle, whilst the same truck tested on a 'truck' duty cycle achieved greater than 70% NO_X reduction. No other experience of SCR retrofitted to HGVs has been identified during this study. However, supplier experience with the retrofitting to trucks of abatement equipment that combines a diesel particulate filter with a diesel oxidation catalyst for combined PM, carbon monoxide and hydrocarbon emissions reductions – a technology that requires a higher temperature threshold than SCR – indicates that exhaust temperatures of trucks in urban conditions may be sufficient for SCR.

2.4.3 Space Constraints on Vehicles

There is a concern that the space envelope available on existing vehicles may be insufficient for the space demanded by SCR equipment. Not all stakeholders share this view however; some suggest that HGVs should have more space for SCR under the chassis or behind the cab.

There is a gap in experience of retrofitting SCR to trucks such that concerns over addressing space constraints for these vehicles expressed by some stakeholders can at this stage only be met by industry confidence and assertions by the retrofitting supply industry. Without further incentives to develop the evidence base on UK trucks this position is unlikely to change. Consultation with stakeholders has yielded the following points, which in some cases are conflicting:

- If the vehicle already has a particulate filter (DPF) fitted, it is highly unlikely that there will be sufficient space available to retrofit an SCR solution behind the DPF (discussions on the operational viability of mixing DPF and SCR systems is discussed in Section 2.4.4). Typically, the DPF may have been fitted taking up 90% of the available space. Consequently, it may be necessary to remove the existing DPF and then retrofit a combined SCR+DPF device, which will have a higher cost. The SMMT have suggested that 6x2 tractor units may require chassis packaging redesign and that SCR units may need to be mounted vertically. Abatement equipment suppliers have confirmed that vertical mounting of retrofit SCR systems has been demonstrated in terms of practicality and reliability;

- Abatement equipment suppliers with experience of retrofitting SCR to HGVs suggest that whether or not a truck can technically be retrofitted with SCR is extremely variable and is resolved on a case-by-case basis;

- For very space constrained vehicles (e.g. low floor city buses), abatement suppliers have produced solutions that fit the available space envelope through flexibility in design and placement (see, for example, Box 1). This experience gives confidence to those abatement equipment suppliers without truck retrofit experience that, should there be sufficient demand for space constrained solutions, retrofitting SCR+DPF to UK trucks should not pose a problem in this respect, and that it is expected there will be very few cases where space constraints will prevent SCR being fitted. Low floor city buses have exhaust systems in confined engine compartments which is not the case for trucks such that truck retrofit is considered by TfL as likely to be more straightforward than bus retrofit in most circumstances; and

- Although there is more experience in the US in retrofitting SCR to trucks, this should not be interpreted as a sufficient solution to possible space constraints as US trucks are less space-constrained. The SMMT suggest that it may not be straightforward in terms of space to retrofit SCR to some specialist HDVs.

The retrofit supply industry appears willing to produce de-NOx systems that demonstrate effectiveness on HGVs if commercial opportunity continues beyond a feasibility stage. It appears that it would be useful for abatement equipment suppliers to engage directly with vehicle manufacturers to investigate further the ease with which the abatement equipment could be integrated into vehicles' existing exhaust systems, and to agree on impacts on vehicle performance and warranties.

2.4.4 Interaction with Existing Aftertreatment Devices

As well as the space constraints considered in the previous section, some abatement manufacturers have expressed concerns over interoperability between DPFs and SCRs produced by different suppliers. However, there are differing opinions between the manufactures consulted regarding the feasibility of retrofitting SCR to vehicles already fitted with PM abatement.

The main argument against retrofitting an SCR system to a vehicle fitted with PM abatement of a different manufacture is that the two aftertreatment devices need to work together. The preferred solution is to fit a combined SCR+DPF system so that each part is designed concurrently in order to optimise the overall system performance. This approach also has benefits for designing the combined system to fit the available space. In addition, a commercial consideration is that should the SCR unit fail to operate correctly it could be as a result of problems with the DPF rather than failure of the SCR unit itself. This poses difficulties in assigning liability and therefore manufacturers may not be willing to fit their SCR units alongside another manufacturer's DPF. Furthermore, some equipment suppliers have indicated their reluctance to share technical data that would be necessary in order to have a functioning SCR after another manufacturer's DPF. All manufacturers agree that it would be possible to retrofit SCR in instances where existing DPFs were manufactured by them as well, as there would be greater understanding of, and confidence in, the specifications of the unit.

However, one of the manufactures consulted does not view this as a problem for SCR units achieving up to 80% reduction, especially on larger systems in which the DPF and SCR units are separately housed rather than integrated. If space requires a compact system then the SCR needs to be integrated directly onto the end of the PM control and there can be practical difficulties with the fittings and connectors. As there is a sensor before the NO_x control system there is not too much concern regarding the exhaust gas properties coming out of the DPF. Whilst there is expected to be variation between different PM abatement units, the engines themselves (especially those over three years old) have similar variations in exhaust characteristics which the SCR or DPF devices must already be designed to cope with. Initial concern was raised by suppliers around compatibility of retrofitted SCR units with existing DPFs from other manufacturers due to uncertainty of N_2O emissions from different engines (of varying ages) and from different DPFs. TfL has since clarified that engine-out or post-DPF N_2O emissions can be measured and are typically below background levels. This suggests that there should not be a compatibility issue with regards to SCR-inlet N_2O emission levels. For clarity, it is the SCR units themselves that can lead to increased N_2O emissions through incomplete conversion over the catalyst.

Some manufacturers felt this was an unnecessary complication because they expect operators are likely to have the DPF replaced at the same time, especially if it was greater than three years old as it degrades with time. In this case they are most likely to fit a combined system in one go.

It would be important for any national certification scheme not to be prescriptive on the topic of whether the existing PM abatement would need to be removed.

For those cases in which, for technical reasons, an existing DPF would need to be removed and a combined SCR+DPF device fitted, the higher associated cost of such a fitting would likely have a disproportionately higher impact for smaller operators. For the same reason, these higher costs may penalise early movers who already have DPFs (retro-) fitted on their vehicles. It is understood from stakeholder consultation that most new Euro IV HDVs do not have DPFs fitted; the exceptions are typically those HDVs that achieve NO_X reductions through EGR rather than SCR solutions. Stakeholders have indicated that there is a cost involved in removing an existing DPF if combined SCR+DPF devices are being fitted, but that currently these costs are included in overall fitting costs. The possibility for partial cost recovery exists if the catalysts can be recycled into newer devices. This is subject to size/shape constraints, existing filters not being damaged and availability of information on the DPF.

2.5 Potential Capacity of the Retrofitting Industry

2.5.1 Suppliers

Up-scaling production for an increased retrofit market is not likely to cause difficulties for the abatement technology manufacturers, as most components are standardised and already manufactured in significantly larger quantities for OEMs. Different manufacturers stated that it could take between a few months to two years to increase the number of ‘off the shelf’ system designs to suit a wider range of vehicles and to tool up to upscale assembly, and for that reason (considering investment is also required) staged uptake by vehicle type (as introduced in Section 2.2.3) is preferred. Nevertheless, despite manufacturers citing that design work is required for trucks which would result in slower roll-out for trucks, manufacturers expect a greater level of standardisation to be possible, which will improve scalability and opportunities to reduce costs. The EIC have suggested the possibility of an EIC-coordinated working group to assist in demonstrating trials of SCR devices retrofitted to HGVs to assist knowledge gain in this area. TfL have expressed the view that any potential scheme introduction should not be assumed to phase-in HGVs at a later date as there is no evidence to suggest that retrofit of SCR to HGVs is infeasible.

Other stakeholders have also raised the important point that abatement equipment should be provided with sufficiently scoped warranty cover, i.e. suppliers have responsibility to ensure the supply chain meets certain standards and to maintain a good level of technical support (even if the equipment is not fitted by themselves). For example, the current London LEZ warranty requirement of two years could be set as a minimum warranty requirement for a potential de-NO_X certification scheme.

Suppliers have indicated their support for longer implementation windows, for example in the form of phased introduction for different vehicle categories, such that demand for equipment would be spread over longer periods. It has been recognised that for a recent deadline for the London LEZ operators ordered parts at a late stage and had to go on a waiting list. A national certification framework in which local authorities may implement local transport measures such as LEZs under their own timescales has the potential to spread demand for abatement equipment both geographically and temporally, considering that suppliers are often national rather than local suppliers.

2.5.2 Fitters

Stakeholders have indicated that a potential bottleneck is with the fitting of the equipment.

A national certification framework in which local authorities may implement local measures such as LEZs under their own timescales is unlikely to spread demand over time for fitting abatement equipment because fitting is considered to be undertaken at a local level. Of course, if demand is high enough, fitting can occur over wider geographical areas, as was the case for the London LEZ.

The fitting of PM abatement equipment thus far for the London LEZ and Reduced Pollution Certificate (RPC) scheme has generally been undertaken by the suppliers themselves although dealers (who were part of the Authorised Examiner Process in which individuals in the company were authorised to fit) ended up doing some themselves, which spread out the demand for fitters quite well. ,

Discussions with stakeholders at the workshop have indicated that suppliers expect to do the fitting themselves where captive fleets such as buses are concerned. The supplier would schedule this directly with the fleet operator sometimes installing the equipment at the operator’s premises to minimise disruption. A possible gap arises with trucks where there may be demand for the retrofit of much smaller fleets including individual vehicles. Suppliers have indicated that in these instances they would expect the truck dealerships to be responsible for the fitting of the equipment following appropriate training from the supplier. The dealership would then provide a warranty on the installation. Truck dealerships are becoming considerably more knowledgeable about SCR itself as it is now included on some newer trucks e.g. Euro V. Where a more bespoke system is required for a particular vehicle type (e.g. where there may be space constraints) then the suppliers would expect to do the fitting themselves.

2.6 Summary

Some stakeholders are keen for the UK to develop its own certification standards for retrofit devices due to uncertainty in how quickly the UNECE Regulation would otherwise take to develop. At least two years is considered necessary from the establishment of the framework and publication of these standards until their application for a local transport measure such as an LEZ. Standards should jointly stipulate requirements for percentage mass emission reductions of NO_X (possibly with equivalency to Euro standards) and NO_2, and to include requirements for emissions of N_2O and NH_3, through consideration of the trade-off among pollutants.

If pursued the framework could provide the possibility for standards to come into force separately for different vehicle types over time, and to provide local authorities the possibility to apply different emission standards. The former has three benefits: (i) to help spread demand temporally across the UK; (ii) to allow local authorities to apply an LEZ just to the vehicle types perceived as being most responsible for local air quality problems; and (iii) to provide additional time for experience to be gained in retrofitting SCR to trucks (for example through pilot trials) as this is a key gap at present. Giving local authorities the possibility to apply different emission standards could provide flexibility to make LEZs more stringent in response to more immediate local air quality concerns, as well as recognising that experience to date of SCR retrofits to buses has in many cases improved Euro II or III vehicles to emission levels equivalent to Euro V.

SCR based systems (SCR or SCR in series with a DPF) appear to be (at present) the only viable retrofit technologies for achieving sufficiency high and reliable NO_X (and NO_2) reductions. Recent research highlighting that real-world emissions from *new* HDVs fitted with SCR can be greater than legislative requirements appears to be solvable for *retrofitted* SCR. This is because it is technically feasible to tune SCR systems for specific drive cycles (rather than just to meet limit values during legally required test cycles), including for HGVs in urban conditions. However, stakeholders have suggested that the identified costs of retrofit equipment may well exceed the projected residual values of the pre-Euro IV vehicles that are being considered for retrofit with a possible implementation date of 2015. This implies that the number of operators that may choose to retrofit vehicles to comply with an LEZ may be lower than those which choose to purchase new or newer vehicles.

Other technical issues identified concerned space constraints for retrofitting SCR, particularly on HGVs. However, abatement suppliers are confident that they can solve this problem through compact devices or through resolution on a model by model basis, and other stakeholders suggest sufficient space should exist behind the cab or underneath the chassis. Some consideration of interaction of SCR systems with existing DPFs may be necessary (but not always), but technical solutions exist for this issue (albeit at a higher cost).

In terms of the overall capacity of the retrofitting industry to meet the potential equipment demands that a national LEZ framework and certification scheme could bring, suppliers expect to be able to meet demand, especially if phased introduction (e.g. by vehicle type or geographically) temporally spreads demand. Fitting of the equipment had been identified as a potential bottleneck for the scheme. In many cases, primarily where captive fleets are concerned, the suppliers themselves expect to undertake the fitting. For smaller fleets including single vehicle retrofits the fitting may be undertaken by a truck dealership following appropriate training from the suppliers. Stakeholder views gathered indicate that it should not be necessary to establish a fitter certification system because the burden of responsibility for correct fitting lies with the equipment suppliers.

3. Administration

3.1 Introduction

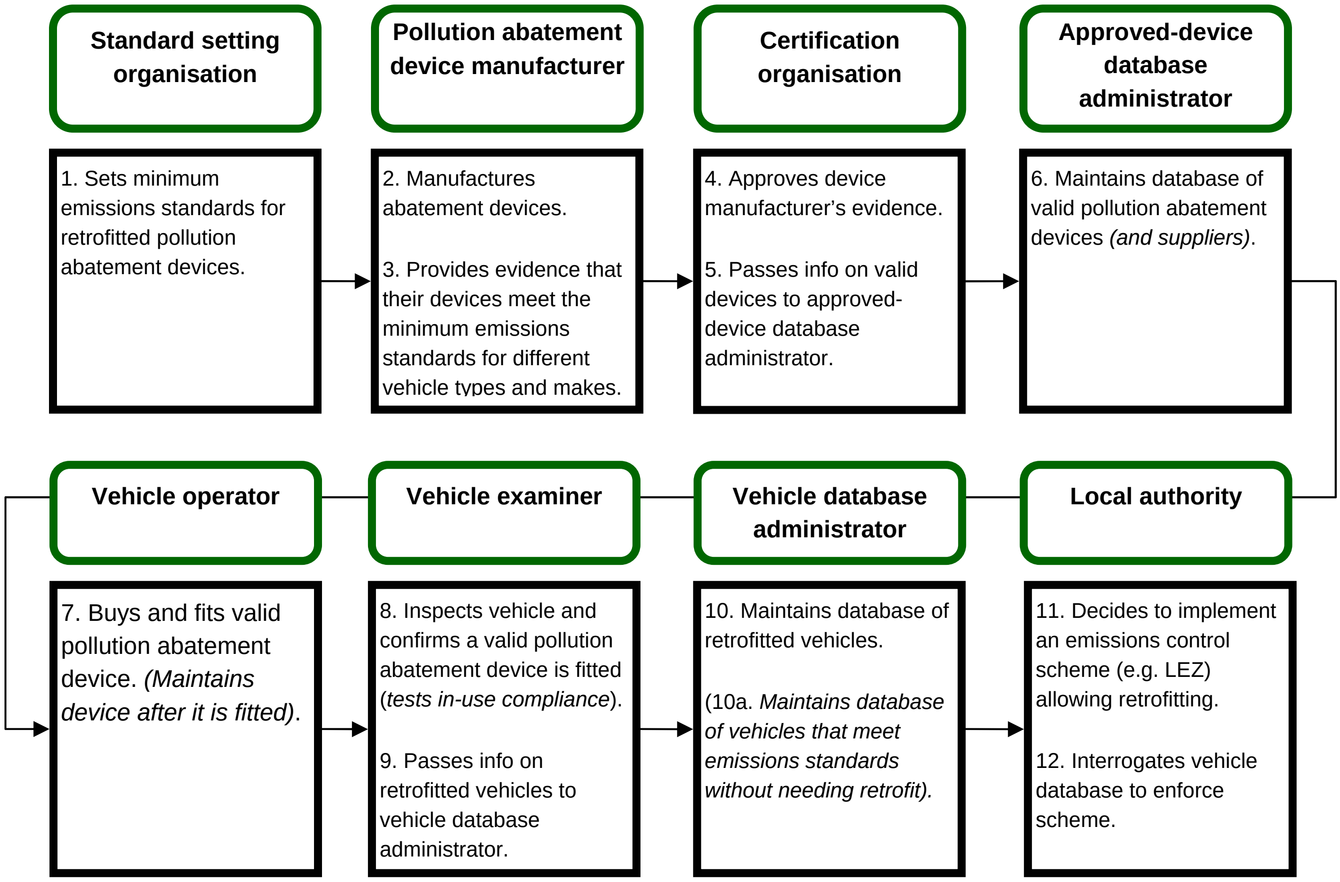
This section investigates how a national certification scheme could potentially be administered. This includes a consideration of overall operation of the scheme; the systems and databases that would be required; possible roles and responsibilities; initial set-up and operating costs and the lead-time that may be required for development and set-up. It has not been possible within the scope and timescales of this study to determine the overall cost of setting up and administering such a scheme. Experience is drawn from other schemes and an assessment is made of how far existing arrangements under the London Low Emission Zone may be applicable for a national certification scheme. The research questions that have helped to shape this section are included in Appendix A.

3.2 Administration Options

3.2.1 Overview

Figure 3.1 demonstrates schematically how a scheme could potentially operate.

Figure 3.1 Diagram of Possible National de-NO_X Certification Scheme



Source: Adapted from Defra specification (2011) "Developing a Certification Scheme for Technology Retrofitted to Heavy Goods Vehicles to Abate Emissions of Oxides of Nitrogen" (based on the model adopted by TfL for the London Low Emission Zone)

3.2.2 Systems / Databases

As illustrated in Figure 3.1, it is considered that two main databases would be required:

- Approved device database: this list would be operated by the relevant certifying body and would contain details of all approved suppliers and devices. This database would need to be made available publicly online to allow operators to identify which devices they can select. It will also need to be provided to the vehicle certification organisation so that they can ensure an approved device has been fitted;

- Approved retrofitted vehicle database: this list would be operated by the relevant certifying body and would contain details of all retrofitted vehicles (including foreign vehicles where feasible). Depending on the final application of the certification framework, this database may also need to contain details of all vehicles that comply with the standard without the need for retrofit i.e. new vehicles that are of a certain Euro standard. This database would need to be made available to local authorities to allow for them to interrogate it for the application of local transport measures such as an LEZ; and

- A separate fitters database (or certification scheme specifically for fitters) is not deemed to be necessary based on discussions with stakeholders at the workshop. In the majority of cases (certainly in the short term and for captive fleets) the fitting is expected to be completed by the suppliers themselves (as described in Section 2.5.2). In some cases it may be completed by the truck dealerships. In these instances it is envisaged that the suppliers would provide appropriate training to the dealerships to ensure it is fitted correctly. In all cases we would expect an operator to approach a supplier at first to agree on the most appropriate system to install as well as who would be most appropriate to install it.

It is vital that there is a clear link between the relevant certification bodies to ensure suitable sharing and transfer of data. For example, two similar databases already exist for the London LEZ with a focus on PM abatement equipment. VCA manage the approved device database, whilst TfL manage the approved vehicles database with daily updates from VOSA. VCA provide VOSA with an updated database of approved suppliers/devices on a regular basis. VOSA then use this information when testing vehicles to ensure that a certified device has been installed. VOSA subsequently send an updated database of approved vehicles (on a daily basis) to TfL (as well as those that have subsequently lost approval at annual tests e.g. if the technology was not working or had been uninstalled). TfL maintains this database (supplemented with data on vehicles that already meet the standard without retrofitting) and uses it for the enforcement of the LEZ. Foreign vehicles that have been retrofitted with appropriate devices can register with TfL and are added to the database (approximately 100,000 are currently registered). TfL investigated the possibility of interrogating foreign databases (e.g. German national LEZ database) for the London LEZ but was unable to secure access and availability of data.

Whilst it is anticipated that similar databases could be used for a national certification scheme, in particular for the approved device/supplier database which is likely to only include a small number of options, a new retrofitted vehicle database (including details of vehicles that already meet certain standards without retrofitting) will need to be established and maintained by a central co-ordinating body. This could be based around the structure and format of the current TfL LEZ approved database. In addition, VOSA has indicated that they would have to make some updates to their existing systems for which they would expect central funding to cover costs. For the London LEZ, TfL underwrote VOSA's set-up costs due to uncertainties over operator demand for certification. Testing fees have been set at a level to recover these costs and VOSA is now in a position to start paying TfL back. There are also likely to be additional costs associated with the training of VOSA testers – or the recruitment of additional staff – to enable them to interrogate data from SCR systems as part of their checks to ensure the device has been fitted and is/has been working correctly. This is considered further in Section 3.2.5.

Whilst it has not been feasible within the scope of this study to work up a detailed estimate of the costs associated with the set-up and operation of the databases discussed above, we understand from discussions with TfL that the capital expenditure to introduce the London LEZ in 2008 was approximately £40 million. This includes all the set-up costs including set up of the service provider operation, camera infrastructure, database/IT systems, website, call centres and the public information campaign. The vast majority of this cost is attributable to the operational infrastructure of the scheme including enforcement cameras and appropriate signage.[14] The total cost for the installation of LEZ signs on Highways Agency, borough and TLRN roads was £3 million. The estimated combined

[14] Personal communication with TfL, April 2011

capital expenditure for extending the scheme to large vans and minibuses and tightening emission standards for lorries, buses and coaches was approximately £8.6m.

Costs could perhaps be relatively lower for a national certification framework considering the existing systems in place and considerable experience gained from schemes such as the London LEZ. This will depend, in part, on permission being granted by TfL to use existing databases and infrastructures.

3.2.3 Roles and Responsibilities

Roles

As illustrated in Figure 3.1 there are five key roles that would need to be defined (excluding equipment suppliers, vehicle operators and local authorities):

i. Standard setting organisation;

ii. Certification organisation;

iii. Approved-device database administrator;

iv. Vehicle examiner; and

v. Vehicle database administrator.

Based on consultation with stakeholders and drawing from the experiences of the London LEZ, it appears to be likely that the following roles may be necessary for a potential scheme:

- The standard setting organisation would likely be DfT in conjunction with Defra;
- It is likely that VCA or EST would independently certify the device suppliers and devices;
- VOSA (or another authorised examiner) would certify vehicles once the abatement technology has been installed. Consultation with EIC indicated that, in order to ensure independence, the private sector ought not be involved in certification; and
- There would need to be an over-arching co-ordinating role in order to supervise the system. There is currently uncertainty regarding which organisation could assume this central role, but it is assumed that it would be likely to be DfT or one of its executive agencies.

Responsibilities

In addition to the need for a body/bodies to establish the standards in the first place and take an over-arching co-ordinating role in terms of managing the main database and supervising the scheme, the main responsibilities relate to the certification process itself. In general, all stakeholders consulted have indicated that the existing process in place for the London LEZ (and RPC) has been successful and for consistency and ease of application they would expect a similar process to be applied for a national certification scheme. HGVs and buses are already familiar with the VOSA testing regime and certification checks can be streamlined with existing annual tests. Whilst there could be the possibility of including the certification tests in the MOT tests, this would involve significant changes to the overall testing process and is not considered realistic.

There are three main components to the proposed certification process (based around existing practices):

i. Retrofit device supplier approval: an independent certification body (VCA or EST) undertakes an annual inspection of each supplier. This assesses that the entire supply chain is able to meet the requirements (e.g. including design supply, sales, fitting, maintenance and warranty). An audit questionnaire was developed for the London LEZ scheme for checking and approving suppliers. It is expected that this process and associated documentation could be applied, with only minor modifications, for the application of a national certification framework;

ii. Retrofit approval: the independent certification body (EST or VCA) inspects emissions test evidence provided by the supplier. This confirms the ability of the adaptation to enable specific engines to meet the required emissions standards. The certification body may also witness specific tests. Approved devices may be published publicly alongside approved supplier's details, for instance, on the VCA website; and

iii. Vehicle certification: VOSA inspect each vehicle annually to confirm that it has been retrofitted with a device on the published approved device list, appropriate to the vehicle and its engine, and it is fitted and working correctly.

VOSA has expressed some concerns about what checks they could realistically do on a retrofitted SCR system. For DPF certification, they undertake a relatively straightforward functional test (a smoke test) to ensure that the device functions correctly. VOSA are limited in the testing that they can perform as they currently lack the equipment and expertise. Consultation with suppliers has indicated that it may be possible for SCR devices to be interrogated by VOSA to confirm that the device is operating correctly, as opposed to having to conduct any real emissions testing. This could be a more straightforward and cost-effect alternative. As discussed previously, suppliers of the equipment have indicated that further work would be required to establish an appropriate mechanism for this element of the certification (i.e. ensuring standard outputs from the SCR unit for VOSA to interrogate) and they have recommended establishing an EIC working group to take it forward. If this were possible, then any additional SCR checks are expected to add around 5 to 10 minutes to the time requirements of the existing VOSA tests (up to an hour). It is unclear at this stage whether incorporating this element into the existing VOSA testing procedure would require any legal changes. Discussions with stakeholders at the workshop were inconclusive. Furthermore, if driver aid warning lights are to be incorporated into retrofitted systems, a similar approach could be used in which standard practice and fitting is coordinated by suppliers.

In addition, due to limited capacity at VOSA testing sites to conduct the initial certification for the London LEZ, certain authorised suppliers/fitters were permitted to do the test themselves and to send the results to VOSA to approve. This may also be required as part of a national de-NO_X certification scheme if any bottlenecks are identified.

3.2.4 Publicity

An important consideration is the necessary publicity required to make relevant stakeholders (for example suppliers, fleet owners, freight operators) aware of the scheme and how they can select an approved device and gain certification. Prior to the introduction of the scheme, TfL launched an extensive awareness-raising campaign to reach out to relevant stakeholders in advance of the London LEZ that involved radio advertising, advertising on billboards and in local press and a new LEZ website. Stakeholders have also been kept informed of any planned changes or expansions made to the existing scheme e.g. Phases 3 and 4 of the London LEZ, effective from 3 January 2012, will affect significantly more vehicle types so a new publicity campaign is being run between January 2011 and March 2012. This campaign includes press adverts, posters at targeted sites, radio adverts and leaflets for distribution to operators. TfL are also engaging with key stakeholders with the aim of:

- Raising awareness of the changes of the new phase;
- Educating operators about vehicles affected;
- Encouraging operators to take timely action; and
- Explaining the benefits of the LEZ.

It has not been feasible within the scope of this study to work up a detailed estimate of the costs associated with any publicity for a national certification scheme, for example for informing operators how they can identify an approved supplier and device. We understand from discussions with TfL based on their experiences with the London LEZ that costs were approximately £5 million when first setting up the scheme and annual costs have fluctuated considerably depending on the different stages of the LEZ. It should be noted that this estimate is based on the costs that were incurred for the London LEZ and are likely to differ for a national certification framework considering it is at a national rather than regional level and is only for the certification aspects i.e. not specifically for an LEZ at this stage. However it is considered likely that the aspects regarding publicity for a national certification framework would be similar to some of those that were undertaken for the London LEZ (e.g. second and third bullet points of above list). Any publicity for local traffic control measures that rely on a national certification scheme would need to be managed by the relevant local or regional authority.

Furthermore, trade associations, such as the Freight Transport Association and Road Haulage Association, play a key role in disseminating information to their members[15]. It would be important to work alongside such associations and involve them at an early stage if a framework were taken forward.

[15] For example, the FTA has produced a compliance guidance note for its members for the London LEZ (http://www.fta.co.uk/export/sites/fta/_galleries/downloads/low_emission_zone/london_low_emission_zone_guide.pdf)

3.2.5 Options for Cost Recovery

This section only addresses cost recovery for the certification and administration of the scheme and not enforcement options for any potential LEZ (this is discussed in Section 4).

The London LEZ was able to utilise much of the existing Central London Congestion Charging Scheme Zone infrastructure (introduced in 2003) including fixed cameras and the associated data management infrastructure. Despite this advantage, the initial set-up costs were significant with TfL placing the total costs in the region of £40 million (albeit this includes a range of cost elements specific to the LEZ itself rather than the certification / administration aspects). It is considered that utilising the existing databases and linkages that have been set up for the LEZ/RPC schemes is likely to be the most cost-effective and practical option. However, as discussed in previous sections, there may need to be some modifications to ensure that there is sufficient capacity and they are suitable for a national scale. It will also depend on relevant permissions being granted in order for these databases to be expanded to the national scale.

In terms of recovering initial set-up costs and ongoing certification costs, the main option appears to be a fee-based system. Under this system, manufacturers and suppliers of devices would be required to pay a fee to gain certification under the scheme. Similarly, vehicle owners could pay to have their adapted vehicles certified. TfL have indicated that the London LEZ certification bodies charge approximately £5k per manufacturer to cover the cost of company approval and device certification, and that this fee does not contribute towards vehicle databases, scheme administration or other setup costs. For comparison, the experience of the Californian Air Resources Board is described in Box 2, for which fees are not charged for certification

Box 2	**Case study: California Air Resources Board (CARB)**
The *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fuelled Engines and Vehicles* was approved by CARB in September 2000. The plan includes measures for various categories of in-use on- and off-road diesel engines. The plan includes a "Control Equipment Verification Program" which provides a way to evaluate the PM emission reduction capabilities and durability of the diesel emission control devices. To date, 52 devices have been verified under the program. The list of approved devices is published online (http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm). CARB does not charge a fee for verification. Such costs are absorbed by CARB internally.	

From a certification perspective, VCA have indicated that their fees are based on the time it takes to undertake a supplier audit, review any evidence as well as attendance at any emission tests, i.e. they aim to recover 100% of the costs of their time. However, only a small number of suppliers (and devices) are expected so this is not likely to have a significant impact. As mentioned earlier, an audit questionnaire has already been established by TfL and a proven process is already in place from the London LEZ/RPC schemes.

On the other hand, VOSA's role would likely to be more resource-intensive as assessment would be at the vehicle level and therefore there would be significantly more checks to be undertaken. VOSA have tried to streamline certification for the LEZ/RPC alongside existing annual tests. It would be important for VOSA to be sufficiently prepared for resourcing the certification in order not to introduce a bottleneck into the system. As indicated by suppliers and discussed in previous sections, it may be possible for VOSA to interrogate an SCR unit to check that it is operating correctly (rather than conducting actual emissions testing which would require new tools and training). The ECU of the SCR system can record if NOx emission reductions are occurring, exhaust temperatures, filter blockages and volumes of liquid present in the reagent tank. An additional sensor would be necessary (at little additional cost) to enable the detection specifically of urea in the reagent tank as opposed to, for example, water. As introduced in Section 2.4.1, SCR systems with closed loop control would have an additional NO_X sensor to allow for data to be recorded on actual NO_X reductions achieved. In order for VOSA to be able to interrogate the SCR unit, it could be possible for abatement manufacturers to provide VOSA with restricted access codes to interrogate the ECU during an annual service/inspection (it would be potentially possible to restrict users from accessing or wiping such data). This would require some industry input and collaboration between suppliers in order to standardise the access protocols, the data in the ECUs and technical coupling. Suppliers consulted appear to be willing to assist on this matter, for example via the establishment of an EIC working group to address this issue.

As discussed in previous sections, VOSA estimate that this interrogation / check would only add approximately 5-10 minutes to the existing vehicle tests. It is anticipated that the costs of this time would be recovered via an application fee to operators. There would also be additional costs involved in training examiners to be able to certify retrofit devices which may be more resource intensive. It may be beneficial for the equipment suppliers themselves to provide this training although there would still be a time cost for the VOSA examiners to attend such training workshops. A broad estimate of the manpower costs associated with attendance at such training events can be derived using the UK Standard Cost Model[16]. Assuming two to three examiners from each of the 97 VOSA testing centres attending a half day training workshop, the manpower costs (in terms of time for attendance) could be in the region of £20-30k. It should be noted that for the London LEZ, TfL underwrote VOSA's initial set-up costs due to uncertainties over take-up. Fees being charged to operators are meant to recover some of these costs and they are now in a position to start repaying some of these costs back to TfL. VOSA has indicated that they would require some form of grant and/or central funding for the initial set-up of a national scheme.

In addition, where an LEZ is implemented a penalty-based system, whereby costs are recuperated through penalties applied to motorists who do not comply with the scheme, could be applied to recover initial and on-going costs. Under the London LEZ, the penalty charge ranges from £500 to £1,000 per vehicle for non-compliance. The scheme was estimated to generate £5m to £7m per year in revenues[17]. Consultation with TfL found that the income generated from these penalties has not covered the total costs of the LEZ scheme. Furthermore, there have been particular difficulties in recovering costs from foreign vehicles that have not complied. One compliance option for operators is to pay a daily charge, but TfL has indicated that so few operators (much less than anticipated) choose this option such that it generates very little revenue.

3.3 Summary

Consultation with stakeholders and a review of impact assessments has shown that the processes in place for the operation of the London LEZ (and RPC) have been largely successful. For consistency, cost-effectiveness and ease

[16] Available from: http://www.bis.gov.uk/policies/better-regulation/policy/simplifying-existing-regulations/reducing-administrative-burdens

[17] Transport for London's Report to the Mayor, April 2007

of application it is suggested that if a national certification scheme were taken forward it should be based around this existing design in terms of key roles, responsibilities and databases/IT systems. Whilst it has not been possible to provide a detailed estimate of the costs associated with initial set-up of a scheme, it is possible that costs could be lower than for the London LEZ set-up considering the existing systems in place and considerable experience gained.

In addition to the databases and systems that would need to be established, an effective publicity campaign is considered to be critical in raising awareness and encouraging operators to take timely action (in particular, if being applied as part of an LEZ). Early engagement with stakeholders is considered a priority.

In terms of cost recovery, the main option appears to be a fee-based system whereby the certification bodies involved in the process charge to certify devices/suppliers and retrofitted vehicles. However it is possible that income generated from fees may not cover the initial set-up costs, especially if operators choose to invest in newer vehicles rather than retrofitting abatement equipment.

4. Enforcement

4.1 Introduction

The enforcement of the use of retrofitted de-NO_X equipment to meet particular emission standards is more difficult than that for PM abatement equipment. This is because PM abatement equipment is considered to reliably continue to abate PM once fitted, whereas de-NO_X equipment – SCR – requires the vehicle operator to regularly top-up with a consumable reagent in order for the device to function correctly.

Section 3 described the processes involved in administering a national certification scheme. This includes the initial certification of vehicles by VOSA which would continue on an annual basis as re-certification to check, in the same manner as that undertaken for the initial certification, that the de-NO_X abatement equipment was still installed and operating correctly. As discussed in more detail in Section 3.2.3, this would involve VOSA interrogating the retrofitted equipment to essentially download data recorded by the device from the past year, and that this process would necessitate a certain amount of standardisation across equipment manufacturers.

Enforcement options for this are discussed in the next section and summarised in Section 4.6. Most LEZs in Europe adopt ‘light touch’ manual enforcement strategies[18] which stakeholders at the workshop appeared to support for adoption in the UK.

The research questions that have helped to shape this section are included in Appendix A.

4.2 Enforcement Options

4.2.1 Overview

The annual vehicle certification process referred to in the previous section is considered distinct from the options available to local authorities to enforce in-use compliance of vehicles operating within defined traffic management schemes such as LEZs. This is because the annual certification cannot answer whether or not a vehicle has complied with a particular LEZ because the data that could be recorded and thus interrogated are not geolocated (i.e. geographically resolved). The annual certification as described can only certify a vehicle for a forthcoming period (e.g. a year) on the basis of the retrospective performance of the device over a past period (e.g. a year). Although by retrofitting de-NO_X abatement equipment, an operator is intending to comply with a particular zone or zones into which the vehicle is to be driven, there is no legal commitment for the operator to continuously comply with the standards set for the zone(s) when the vehicle is driven outside of the zone(s). However, it has been suggested that the concept of requiring a retrofitted vehicle to continuously comply would mean that both retrofitted vehicles and vehicles with OEM SCR would meet the same emission standards. For when the vehicle is

[18] Sadler Consultants (2010) Low Emission Zones in Europe. Report for the UK Department of Transport.

operated within an LEZ, both the operator and the local authority wish to know that the vehicle is compliant with the LEZ requirements.

Given the legal requirement – and potentially a fine or other disincentive for non-compliance – operators may wish to know in real-time whether or not the vehicle is compliant. Real-time operational status of SCR units is technically feasible, but stakeholders indicate that this level of information is normally hidden from the driver and is retained just for servicing. Discussions among stakeholders indicated a consensus that it should not be difficult to include a simple red/amber/green driver aid to indicate whether the SCR system has been operating within required limits during a specified period. This option would essentially function as self-enforcement, and could be coupled with automatic logging to allow the annual certification to determine if the driver responded to warning lights, or the number of periods or total period of warning lights over 12 months. This is considered by some stakeholders to be sufficient for any enforcement. Abatement equipment suppliers further indicate that their contractual obligations through products' warranties as provided in a competitive market leads to a certain level of self-policing.

A number of enforcement options exist, which have varying cost implications and varying levels of compliance assurance. The main options are described in the following sections. Not described in this work are the supporting measures that could be taken by local authorities to assist enforcement, such as licensing, partnerships with operators, contracts for public service vehicles and planning conditions. Supporting mechanisms could be used to initiate dialogue between scheme regulators and vehicle/fleet operators about forthcoming LEZ restrictions.

4.2.2 Options Assuring one-off Compliance

Windscreen Sticker

The annual certification of vehicles by VOSA would lead to a classification of vehicles into particular Euro standard equivalent classes. Whilst this information will be held on a database, this classification could be made visible on a vehicle through the issuing and display of a sticker for the windscreen. Local authorities could then set the LEZ requirements according to the particular stickers issued. This system is that used by the national LEZ framework in Germany, as described below in Box 3. The sticker displayed within the vehicle can be used for manual enforcement of the LEZ. The sticker could separately identify the PM and NO_X emission standards achieved, although it is worth noting the debate on whether a traffic control measure should rely on different standards for different pollutants (see Section 2.2.4).

Costs for dealing with retrofitted vehicles under such a system are expected to be low. The system would not need significant additional resources beyond the annual certification by VOSA set out in Section 4.1. However, *all* HDVs would need to display the windscreen stickers. The UK database of vehicle registrations does not currently hold information on the Euro standard of the vehicles (in contrast to the German system) which it would need to do in order to issue compliant vehicles with stickers. DfT has estimated that the costs to make this upgrade to the database may be up to £1m. Manual enforcement would require additional funding for the personnel to undertake enforcement, but this could be incorporated into existing roles, for example local parking wardens. This strategy would also allow local authorities to make varying levels of investment in enforcement. There remain options also as to what penalty for non-compliance to impose, which may be related to cost-recovery considerations, although experience in Germany is that most financial penalty tickets issued have been for foreign vehicles which has made cost recovery more difficult and expensive. Points could be issued on drivers' licenses for non-compliance.

The main disadvantage of a sticker-based system is that it is unable to guarantee that the retrofitted technology is achieving the required emission reductions on an on-going basis. For SCR systems, the concern is that the user is required to top-up with Ad-blue (at cost) in order for NO_X reductions to take place. Unlike SCR fitted to new vehicles, retrofit systems are unable to link to the engine management system to impose power limits if the reagent is not topped up. The sticker-based system used in Germany is focussed on PM enforcement; there is no incentive for operators to disengage PM abatement equipment once it is fitted, such that it is much more reliable to assume that once PM abatement is fitted, devices continue to be active. There is also a small concern that sticker-based systems could be open to forgery.

Box 3 Case study: LEZs in Germany

National LEZ framework

The German government adopted a national labelling scheme, which provides the basis to control emission related traffic restrictions in LEZ in Germany. The focus of the national LEZ scheme is currently on reducing PM emissions, and the scheme applies to both light duty and heavy duty vehicles. The scheme, which has been in force since March 2007, introduced 4 pollution classes, according to the emission on the right hand side.

Vehicles not meeting any of these criteria belong to pollution class 1. They cannot be exempted from any traffic ban. An amendment to the national vehicle registration ordinance sets out the minimum efficiency PM abatement equipment needs to fulfil in order for retrofitted diesel vehicles to be considered as a lower polluting class (higher numbered labelling).

sticker:	2 S-UM43	3 S- UM43	4 S-UM43
minumum criteria for Diesel vehicles	Euro 2, or Euro1 plus particle filter	Euro 3, or Euro 2 plus particle filter	Euro 4, Euro 3 plus particle filter
ban for Diesel veh. older than ...	1992	1996	2000
minimum citeria for petrol cars			Euro 1 plus catalytic converter

The cities or regions then decide whether, where and when to introduce an LEZ, and what emissions standards will be required. To show compliance, operators must purchase and display a sticker in the windscreen. This sticker is then valid for all LEZs in Germany. Proof of an emissions standard, which is provided on German vehicle registration papers, is needed to purchase the sticker. Stickers can be purchased from the vehicle registration authorities, authorised local garages and vehicle test organisations such as TÜV and DEKRA. Many hotels in LEZ cities also offer the stickers for guests if they receive the requisite documents in advance. Stickers can also be ordered by email from the vehicle registration authority if the required documents are provided (a copy of the vehicle registration and/or any official document showing the date of entry into service and the type of the vehicle).

Enforcement

Enforcement of LEZs is undertaken manually through visual inspection of stickers displayed in windscreens. Monitoring of parked vehicles is conducted by parking attendants (managed at the borough level). Police check vehicles during routine traffic checks. Even if the vehicle meets the emissions standard of an LEZ, if there is no sticker in the windscreen and the vehicle is in LEZ, the operator has committed an offence. The penalties for non-compliance are a fine (€40) and one point in the national traffic penalty register for German vehicles. So far, approximately 40,000 penalty fines have been issued. Most of these have been to foreign vehicles and it is reported that it has been difficult to chase payment for these fines.

The sticker system was chosen for its simplicity and due to cultural considerations that the German population are very concerned with data privacy. There is anecdotal suggestion that there is a positive psychological effect of having a sticker system, in that everyone can see the sticker and therefore is aware if a vehicle is illegally in an LEZ. The sticker system was also considered to have low administrative costs.

Sources: Personal communication with M Lutz; and Lutz, M. (2009) Workshop on 'NOx: Time for Compliance', Birmingham. The low emission zone in Berlin – results of a first impact assessment.

Automatic Number Plate Recognition

An extension of the windscreen sticker option described above is to use the database of vehicle emission standards associated with vehicle number plates (as developed from the annual certification by VOSA), coupled with automatic number plate recognition (ANPR) using fixed road-side cameras (rather than manual visual inspection of windscreen stickers). This is the approach currently used for enforcement of the London LEZ. ANPR allows for an increased level of enforcement compared to manual inspection due to its ability to check vehicles on a continuous basis. The second advantage of ANPR over sticker-based systems is the reduction in possible forgery of stickers.

However, the disadvantage of ANPR systems is that they are expensive. Aside from infrastructure set-up costs, the on-going costs for ANPR systems have been indicated by one stakeholder to be 6 pence per license plate recognised (this figure has not been verified). The London LEZ uses ANPR systems for enforcement, but it is recognised that it benefited from being able to use infrastructure (cameras and back office database systems) already set up for the central London congestion charge zone, although given the wider geographical scope of the London LEZ additional cameras were necessary to install. Anecdotally, it has been suggested that if the congestion charge scheme infrastructure hadn't already been in place, TfL may not have opted for ANPR enforcement of the London LEZ. However, it is recognised that for smaller urban areas, such ANPR systems may not be as extensive as required for London, for example if only a handful of major routes are used by HGVs to enter an urban area.

An additional option for a system set up to use ANPR to retrieve information from a vehicle database is to use mobile cameras for spot-check enforcement rather than fixed roadside cameras. This has the advantage of being able to be deployed on a scale commensurate with available budgets, but reduces the number of vehicles that may be checked.

Emissions Testing of Vehicles

The annual certification of vehicles referred to in Section 4.1 is suggested to involve VOSA checking SCR device functionality by interrogation of stored data. An alternative to this option, could involve emissions testing of vehicles on chassis dynamometers by independent bodies. This option has the advantage of being able to verify the actual emissions from the vehicle during real-world testing. However, the drawbacks of this option are significant such that this option is not considered feasible. These include: (1) there is currently only one UK-based emissions test facility (Millbrook Proving Ground) capable of chassis dynamometer testing a full range of HDVs; (2) tests are estimated to cost around £10k per HDV; (3) the option would involve an additional downtime for vehicles on top of the annual certification by VOSA; and (4) this option is unable to ensure on-going compliance.

4.2.3 Options Assuring on-going Compliance

Overview

All of the enforcement options described above in Section 4.2.2 are based on assessing compliance of a vehicle on the basis of its emission performance at a certain point in the past. For SCR systems, as noted in Section 2.3, there is a need for the operator to top-up with urea on an on-going basis if NO_X reductions are to be achieved. There is therefore a concern over on-going compliance of vehicles retrofitted with SCR, such that there is a desire for local authorities who introduce an LEZ to ensure emission reductions are achieved by vehicles. Nonetheless, stakeholders including local authorities have indicated that they are strongly in favour of 'light touch' enforcement methods, i.e. those with the least possible public sector intervention and oversight.

Ensuring continued compliance of vehicles can only be legally enforceable whilst the vehicle is operating within LEZs, unless the certification scheme requires operators to comply at all times. This fact leads to an uncertainty for interrogation of data recorded by the SCR unit as described in Section 3.2.4 in that although the operator may have made a commitment through retrofitting SCR to comply with a particular emission standard, the operator *must* only comply whilst operating in defined areas. Without VOSA having the knowledge of where the vehicles has been operated, it is not possible to retrospectively enforce compliance for a particular LEZ (it is however possible for VOSA not to re-certify a vehicle on the basis of it not having met a particular emission standard).

In-situ Monitoring in General: Recording and Storing Data

Stakeholders have suggested that in-situ monitoring of real-time SCR equipment functionality can be inferred from knowledge that the reagent is present (and that it is not another liquid, e.g. water). An additional sensor would therefore be necessary to detect that a liquid is present in the reagent tank, and that it is the correct reagent. However, this approach does not ensure necessarily that sufficient NO_X reductions take place, because it is also necessary for the exhaust gas temperatures to exceed a threshold as described in Section 2.4.2. Current retrofit SCR systems do record exhaust gas temperatures, filter blockages and volumes of liquid present in the reagent tank, but are unable to control the engine ECUs to, for example, de-rate engine power should the SCR unit be deactivated for any reason. The EIC have suggested that they could undertake further work on identifying the best variables to record in such instances.

A solution to this issue is for SCR systems to adopt closed loop control which has the functionality to measure the NO_X reductions achieved over the catalyst (and, which has additional benefits as described in Section 2.4.1). Some SCR systems already adopt this control measure. Closed loop control requires an additional NO_X sensor. Stakeholders consulted have suggested that NO_x sensors currently cost around £200 to £300 and are sold at prices (i.e. including mark-up) of around £650. Three years ago the unit cost was around £650 so it can be seen that the unit costs have decreased as demand has increased; the expectation is that if demand increases above 4,000 units per year the unit cost may fall to around £170.

The on board computer would need to log and store the emissions data for subsequent download. This later download would be during the annual VOSA certification, but as an enforcement route, could additionally be on an ad-hoc manual basis within an LEZ. There could be a requirement to retain such logged data for a defined period of time, which could be required to be made available to local authorities for enforcement purposes upon request. It would need to be determined which actors would need to be involved to test and check data. Penalties for non-compliance would need to be issued.

Discussions among stakeholders have suggested that it would be reasonably straightforward to include an extension of real-time monitoring to provide the driver with a simple red/amber/green light to indicate operational status of the SCR unit. The logging of such information could be used for inspection either at ad-hoc intervals or annually during VOSA's inspection. For example, thresholds of operational time at each of red/amber/green status could lead to a simplification of interrogation for operators and regulators.

In-situ monitoring: Geolocating Vehicles using GPS

The option of in-situ data monitoring and storing for later download, as presented above, still suffers from the identified problem of not knowing when the vehicle has been operated within a LEZ. If global position system (GPS) devices were coupled with the NO_X sensor to record in real-time the vehicle position and the SCR NO_X abatement efficiency then enforcement of an LEZ could be undertaken more rigorously. The enforcement could be undertaken either on an ad-hoc basis (e.g. road side SCR system interrogation) or be incorporated into the annual VOSA certification (at cost).

However, this option does have some data privacy concerns, particularly for HGV and private bus operators (it should not be a problem for public bus operators as they follow standard bus routes). In order to address such concerns, there is a possibility for GPS devices to not pinpoint vehicle locations, but to instead indicate whether or not a vehicle is within a particular LEZ or not (this would reduce but not eliminate the privacy concerns). Such a set-up would require additional costs for development of appropriate devices and for on-going updating of devices as and when new LEZs are brought into force.

Buses may already incorporate GPS devices in order to link in to live bus information systems (see for example Box 4), such that hardware costs of such systems could be reduced. However, cost information has not been sought for this option due to likelihood of privacy concerns outweighing its benefits.

Box 4 Case study: Trials of SCR systems retrofitted to buses in Oxford

Following initial trials more than 5 years ago involving SCR retrofit undertaken in partnership between Oxford City Council and a local bus operator, the bus operator has retrofitted SCR to a number of buses operating in the city centre. This is in advance of the LEZ that has been declared for Oxford city centre to begin in 2014.

In-situ monitoring of emissions from the retrofitted buses has been undertaken in December 2010. The real-time telemetry data demonstrate NO_X reductions of around 80% across varying ambient temperatures. Recorded exhaust gas temperatures exceed the minimum injection temperature threshold across the bus' stop-start cycles, even though the bus schedules include stopovers of between 2 to 10 minutes in which engines are switched off.

The in-situ monitoring results have been logged in real-time in combination with GPS devices which are linked into the existing 'OxonTime' live bus stop data stream that relies on real-time GPS.

In-situ Monitoring: Transmitting Data in Real-time

The option to have telemetry fitted to vehicles (closed loop real-time NO_X sensors coupled with transmitters operating on for example the GSM network) to assess real-time compliance has the potential to provide a much more rigorous enforcement of standards. This option solves the concern of whether users ensure the urea reagent is topped up. This option would incur upfront costs for the modem onboard the vehicles, and on-going collection (and analysis) of data. There is a large IT setup aspect to any system that collects real-time data. An example of the use of this level of monitoring (used for informational rather than enforcement purposes) is a fleet of Belgian buses retrofitted with SCR+DPFs. It is our understanding the TfL have recently obtained a quote for a system with real-time data transmission and the costs were considered significant and probably prohibitive.

Data privacy concerns for this option are high. It is expected that these concerns may be higher than those associated with CCTV and ANPR as this option continuously records and transmits data in real-time regardless of location, compared to CCTV/ANPR which captures information for a particular location. Furthermore, data associated with this enforcement option must be geolocated in order to assess whether the vehicle is within the boundaries of a LEZ. In order to resolve this issue, real-time telemetry would either need to be coupled with GPS as described above, or coupled with ANPR which would be able to identify when the vehicle entered a LEZ.

Remote Sensing of Exhaust Emissions

Emission concentrations in vehicle exhausts could be monitored remotely using infra-red spectroscopy. Such techniques are most suitable for buses due to the fixed height of the exhaust. Feasibility concerns include variability of NO_X emissions in vehicle exhausts due to vehicle driving patterns, vehicle loading, size and whether the SCR unit is at operation temperature. Therefore this option is not considered by stakeholders to be sufficiently robust or accurate in order to be able to use it as an enforcement technique. Nonetheless, the option could still be an effective measure for policing a scheme especially if operators are unaware of the measurement's limitations. For example, it could act as a visible deterrent and therefore mitigate against deliberate non-compliance.

4.3 Costs of Enforcement

Implementation costs will vary significantly with factors such as the size of city or urban area, whether manual or automatic enforcement is used as well as the overall level of ambition in terms of compliance.

Sadler (2010) has summarised available enforcement cost data for European LEZs.[19] Implementation of Dutch LEZs in the manual enforcement stage has cost an estimated €100,000 to set up for an average city, with annual enforcement costs around €75,000. Expected costs in Odense (Denmark) give set-up costs of around €60,000 and annual enforcement costs of around €17,000. Danish enforcement is undertaken manually, focused at HGV unloading points and parked vehicles, and then combined with regular police activities, which may help explain the lower costs. These are also anticipated costs as the scheme is not yet in place. The costs of London LEZ enforcement were discussed in Section 3.2.

Additional cost estimates for enforcement of an LEZ using ANPR for a city that has considered implementing an LEZ have been provided and include the following[20]:

- For a mobile-ANPR based system using five vans operating throughout the year, which provides a flexible, deterrent-based approach to encouraging compliance, set-up costs of £2m and annual running costs around £2.2m; and

[19] Sadler Consultants (2010) Low Emission Zones in Europe. Report for the UK Department of Transport.

[20] Confidential source.

- For fixed roadside ANPR cameras (at least 30) at all major city entry points as well as key junctions, supported by two mobile ANPR vans, set-up costs may be around £10.6m, with annual running costs around £3.4m.

For the above-quoted ANPR cost estimates, which includes costs of marketing and legal aspects, the confidential source indicates that such a scheme would be unlikely to be self-financing.

Table 4.1 provides an overview of the different enforcement options, anticipated level of compliance and comparative costs.

4.4 Exemptions

It is recognised by stakeholders and from experience of other schemes that there may be a need to exempt some vehicles from compliance with LEZs. However, in order to streamline schemes, the number of exemptions should be minimised.

For the London LEZ, exemptions have been granted for military vehicles, vehicles built prior to 1973 and specialist non-road going vehicles designed and built for mainly off-road use. Additionally for the London LEZ, certain showman vehicles can obtain a 100% discount from the daily charge (which in effect provides an exemption but has a separate legal status). In Germany, two-wheelers, vintage cars, off-road vehicles, police, fire brigade and emergency vehicles are exempted from the national LEZ framework.

The application of exemptions is a separate matter from that of operators that would need to bear costs for compliance but which have specific-use vehicles which may be more costly to make compliant. Some stakeholders have indicated that there may be need to consider providing operators in this category access to grants to help meet the costs of compliance. No specific examples have been identified of grant schemes being applied for specific-use vehicles (although an example of grants being made available for *all* retrofitting operators is the LEZ introduced in Norwich city centre).

4.5 Non-UK Vehicles

Most LEZs do not make exemptions for foreign vehicles. Enforcement of LEZs for foreign vehicles however, in particular the debt recovery from foreign vehicles, is not as straight-forward as for domestic vehicles. The options for foreign vehicle enforcement are:

- Bi-lateral agreements;

- Through private debt collection agencies (often for decriminalised enforcement), for example Euro parking Collection Plc. TfL's experience in this route is that fee recovery is low;

- Taking the vehicle off the road or forbidding its entry is possible for non-EU vehicles where manual enforcement is used; and

- Foreign vehicles can be required to register (as for the London LEZ, and planned for the Netherlands), as there is no other way to identify their compliance.

No other experiences with these foreign vehicle enforcement methods have been identified.

There are EU-level proposals (which have reached Council approval at second reading)[21] for a Directive on improving cross-border exchange of information on road safety related traffic offences. It is unclear at this stage whether this will lead to improvements in foreign vehicle enforcement in LEZs through enhanced access to foreign vehicle databases.

It would be advantageous for there to be a harmonised certification scheme across the EU or at least a joined up approach between Member States as this would assist the UK in dealing with foreign vehicles in UK LEZs (and vice-versa). As such, this supports the argument for the UK to actively contribute to the UNECE discussions on certification standards if neighbouring EU Member States and the UK collectively adopted such UNECE standards (see Section 2.2.2).

4.6 Summary

The annual vehicle certification described in chapter 3 can only conclude the emission standard of a particular vehicle, and cannot – as it is currently envisaged – be used check whether or not a vehicle has complied with a particular LEZ because it is unknown where (and when) the vehicle was operated.

This chapter has presented a number of options that could be available to local authorities for enforcement of schemes such as LEZs. There is an important distinction necessary to be made when considering retrofitting of SCR systems, as compared to PM aftertreatment devices. This distinction is that SCR requires an on-going maintenance by the operator of filling up an additional on-board tank to provide the reagent that facilitates NO_X reduction. As such, there is a desire for local authorities to be assured that emission reductions targeted by an LEZ are achieved in practice. The enforcement options considered in this chapter offer alternative routes for achieving this aim.

However, stakeholders seem to be in agreement on the wish to keep the level of enforcement as light as possible. In some cases, local authorities (for which buses rather than HGVs have been their primary concern) have suggested that they would strongly consider relying solely on the annual certification (as described in Chapter 3) if that certification is sufficiently robust.

Table 4.1 summarises the enforcement options presented in this chapter. The options set out are not necessarily mutually exclusive; a local authority could choose to employ multiple enforcement options. This summary does not assume that the certification scheme will require operators to meet standards at all times (as opposed to just within for example LEZs).

[21] http://ec.europa.eu/prelex/detail_dossier_real.cfm?CL=en&DosId=196862

Table 4.1 Overview for Enforcement Options of Ability to Assure Compliance and Relative Total Costs

Enforcement option	Compliance assurance (one-off)	Compliance assurance (in-use)	Relative total cost for set-up and operation
Annual vehicle certification by VOSA through interrogation of SCR for operational parameter data	Yes	None. Is able to download data from the past year, but cannot verify whether the vehicle operated in the LEZ.	(Required for certification scheme)
Windscreen sticker, manually enforced	Yes	Low. Enforcers must assume that a vehicle with appropriate sticker continues to comply. Vehicles without stickers can easily be identified.	Low/Medium. An upgrade to the UK database of vehicle registrations would be necessary to capture Euro standard information.
Automatic number plate recognition from fixed road-side cameras linked to VOSA database of certified vehicles	High. Systems able to cross-check vast majority of vehicles entering LEZ with database of certified vehicles.	None. Unable to assess on-going compliance in LEZs	High
Automatic number plate recognition from mobile cameras linked to VOSA database of certified vehicles	Low. Spot-checking can only cross-check a minority of vehicles entering LEZ with database of certified vehicles.	None. Unable to assess on-going compliance in LEZs	Low/Medium
Emissions testing of vehicles on chassis dynamometer by an independent body. Annual basis or ad-hoc.	Medium. Accurate testing for real-world conditions. But high time demands per vehicle and current limited testing facilities.	None. Unable to assess on-going compliance in LEZs	Very high (£10k per vehicle).
In-situ monitoring of NO_X emission reductions using closed loop control; storage of data	Yes	None. Is able to download data from the past year, but cannot verify whether the vehicle operated in the LEZ.	As per VOSA certification. Additional costs of NO_X sensor low, and may already be necessary to meet standards for controlling non-regulated pollutants.
In-situ monitoring of NO_X emission reductions using closed loop control coupled with GPS logger; storage of data.	Yes	High. Able to measure and record NO_X emission reductions coupled with exactly when the vehicle is operated with LEZs. Privacy concerns.	Medium
In-situ monitoring of NO_X emission reductions using closed loop control; transmission of data in real-time to central database. ANPR.	Yes	High. Able to measure and record NO_X emission reductions coupled	High. Both IT setup costs and ANPR.
Remote sensing of exhaust emissions	N/A	Medium. Is able to spot-check exhaust emissions within zones. Limited applicability to HGVs. Evidence gap on ensuring methods are sufficiently accurate and robust for enforcement purposes. Could be visible deterrent to mitigate against deliberate non-compliance.	Variable. Spot-check enforcement can be undertaken at a greater or lesser extent according to demand.

Note: The indication of possible costs in this table may differ if PM certification was also included.

5. Conclusions and Next Steps

5.1 Conclusions

This report has summarised the evidence gathered during the study through a literature review, stakeholder consultation and through a stakeholder workshop on a range of topics including the level at which any standards could be set, the technologies available for abatement and practical aspects related to the way in which any certification framework could be established and applied.

Emission Standards and Abatement Options

In terms of the options available to the UK for a certification scheme, some stakeholder would like the UK to develop its own certification scheme for retrofit devices. Once published, at least two years is considered necessary until their application for a local transport measure such as an LEZ. Standards aimed at NO_X reduction will need to jointly stipulate requirements for multiple pollutants (NO_X, NO_2, NH_3, N_2O) and could jointly consider PM and NO_X. The only viable technologies identified in this study are SCR and SCR combined with DPFs. The study has identified the capital, fitting, maintenance and running costs for SCR retrofit technologies. However, stakeholders have suggested that the identified costs of retrofit equipment may exceed the projected residual values of some pre-Euro IV vehicles that might be considered for retrofit with a possible implementation date of 2015.

A potential national certification scheme could be flexible in both providing the possibility for standards to come into force separately for different vehicle types over time, and by providing the possibility to apply different emission standards. These flexibilities have benefits of spreading demand for equipment, allowing local authorities to tailor local traffic schemes to local situations and potentially providing an opportunity for suppliers to gain experience in retrofitting SCR to trucks. However, some stakeholders have expressed reservations over complexity for operators of there potentially being different emission standards in force in different urban areas or different Euro standard requirements for different pollutants.

Evidence gathered suggests that SCR retrofitted to HDVs can be tuned specifically to achieve sufficient NO_X (and NO_2) emission reductions in urban conditions (in contrast with recent literature highlighting SCR units fitted to new Euro V vehicles are not achieving expected NO_X emission reductions in urban conditions). Other technical issues identified concerning SCR retrofits include space constraints, particularly on HGVs. However, suppliers appear confident that they can solve this problem, as well as cases in which vehicles are already fitted with DPFs.

The retrofit supply industry is confident in meeting the demand that would be created by such a scheme, especially if phased introduction temporally spreads demand. Fitting of the equipment had been identified as a potential bottleneck for the scheme. In many cases, primarily where captive fleets are concerned, the suppliers themselves expect to undertake the fitting. For smaller fleets including single vehicle retrofits the fitting may be undertaken by a truck dealership following appropriate training from the suppliers. Stakeholder views gathered indicate that it should not be necessary to establish a fitter certification system because the burden of responsibility for correct fitting lies with the equipment suppliers.

Administration

Consultation with stakeholders and a review of impact assessments has shown that the processes in place for the operation of the London LEZ (and RPC) have been largely successful. For consistency, cost-effectiveness and ease of application it is suggested that if a national scheme were to be established then it should be based around this existing design in terms of key roles, responsibilities and databases/IT systems. Whilst it has not been possible to provide a detailed estimate of the costs associated with initial set-up of a scheme, it is possible that costs could be lower than for the London LEZ set-up considering the existing systems in place and considerable experience gained.

In addition to the databases and systems that would need to be established, an effective publicity campaign is considered to be critical in making relevant stakeholders aware of the scheme and how they can select an approved device and gain certification (in particular, if being applied as part of an LEZ). Early engagement with stakeholders is considered a priority.

In terms of cost recovery, the main option appears to be a fee-based system whereby the certification bodies involved in the process charge to certify devices/suppliers and retrofitted vehicles. However it is likely that income generated from fees may not cover all of the initial set-up costs.

Enforcement

It does not appear that the annual vehicle roadworthiness inspection could be used to check whether or not a vehicle has complied with a particular LEZ because it is unknown where (and when) the vehicle was operated. This statement only holds if the certification scheme will require operators to meet standards at all times (as opposed to just within e.g. LEZs).

A number of options for enforcement of schemes such as LEZs have been described in the report, some of which attempt to address the concern over in-use compliance for vehicles fitted with SCR due to the requirement of such systems for the operator to regularly top-up with a reagent. Local authorities will wish to ensure that emission reductions targeted by an LEZ are achieved in practice, but high levels of assurance are only likely to be achieved through expensive and highly specified technical solutions which could have data privacy concerns. Enforcement options identified include windscreen sticker-based manual enforcement, automatic number plate recognition systems (both roadside and mobile), remote sensing of vehicle exhausts, and various in-situ monitoring options including the transmission of real-time NO_X reduction data. The final choice (or combination of choices) for a particular LEZ would depend on a number of factors including the level of compliance, funding available and location specific variables e.g. number of access points to a particular LEZ. Stakeholders – including local authorities – have given support to 'light touch' enforcement options such as the inclusion of driver aid warning lights, and the possibility for the annual certification to be used (through interrogation of stored data) to determine if the vehicle has been operated in compliance.

5.2 Evidence Gaps, Uncertainties and Further Work

Key evidence gaps, uncertainties and potential areas for further work that appear to remain include the following:

- **UNECE Draft Regulation on requirements for retrofit emission control devices**. This draft regulation is currently still being debated and developed. Current conclusions on the UNECE Draft Regulation are uncertain and subject to change;

- **Experience of retrofitting SCR to trucks**. There appears to be little experience worldwide in retrofitting SCR, and even less experience in Europe. Gaining experience in this area would allow for greater certainty in resolving some of the technical questions addressed in this report such as;

  - Is there sufficient space on UK trucks to retrofit SCR?

  - Will trucks retrofitted with SCR operating in urban experiences achieve sufficient NO_X and NO_2 reductions *in practice*?

- **Central co-ordinating body** to manage the main databases and supervise the overall scheme. Currently assumed to be DfT or one of its executive agencies;

- **Costs of modifying existing and/or developing new databases/systems** for administering a national certification framework and publicity requirements;

- **VOSA testing of SCR devices.** Suppliers have indicated that they could develop their devices to allow VOSA to interrogate the device when checking the vehicle rather than having to undertake any emissions tests as such. This will be reliant on the suppliers agreeing a common suitable approach. This also links to discussions concerning the ability for suppliers to include a simple red/amber/green driver aid to indicate whether the SCR system has been operating within required limits during any specified period;

- **NO_X emission projections from HDVs in urban areas**. The contextual analysis included in Section 2.2.1 set out the projected national NO_X emissions from HDVs. Some local authorities consulted during the study have indicated that they do not necessarily have access to sufficient data on emissions for different vehicle categories at the local level in order to make informed decisions; and

- Whether or not operators with SCR retrofitted should be obliged to comply with nationally certified standards even when they are not operating within LEZs.

Appendix A
Research Questions

The project specification research questions that have framed this study are included below.

Section 2.2 Options for emission standards
• Could a UK scheme adopt existing standards, or ones that are already being developed? (For example, the UNECE GRPE working group is currently seeking to establish a standard for retrofit technology aimed at reducing both NOx and PM_{10} emissions from heavy duty vehicles). If so what would the issues be with adopting these standards? • If the UK Government decided to develop a set of standards, how long would they take to develop and agree, and who would need to be involved? • Is there a trade off between simplicity and effectiveness? If so, what are the key issues and the impacts of choosing different options?
Section 2.3 Technologies available for compliance
• What abatement options are available for compliance with possible emission standards? • How much will retrofitting NOx abatement technology cost operators (both initial purchase and fitting costs and ongoing maintenance and refilling costs)? How might these costs change using different assumptions for levels of demand? • What emissions reductions could be expected for various vehicle types using current retrofit technology? Would these come at the expense of increased fuel consumption and carbon emissions?
Section 2.4 Viability issues and operational difficulties
• Are there any heavy duty vehicles that it would be difficult to retrofit with NOx abatement technology or to make compliant, for example for reasons of space? If so, why, how many and of what type? • Could retrofitted NOx abatement technology cause any operating difficulties for vehicles?
Section 2.5 Potential capacity of the retrofitting industry
• How long would it take for the pollution abatement industry to gear up to provide kit for large numbers of emissions control schemes? • What are the barriers for industry gearing up and how could they be overcome? • At what level would demand be likely to cause supply problems leading to delays and uncertainties for operators?

Section 3.2 Administration options
• What systems/ databases would be necessary in order to operate the scheme? How would local authorities interact with the system? • What level of investment would be necessary to establish and operate them? How long would they take to develop? • Who could administer these systems? Could this be done entirely by the private sector? What is the minimum possible involvement for DfT Executive Agencies? • How might certification and other administration costs be covered by or recovered from equipment manufacturers or vehicle operators? • Could any system be based on the existing arrangements for the London Low Emission Zone?

Section 4.2 Enforcement options
• What are the options for enforcing the standards, both at initial fitting and in-use? What are the cost and practical implications of the options and who would pay? • To what extent could the various options work if local authorities opted for different methods to enforce individual emissions control schemes? For example, some may opt for automatic enforcement using Automatic Number Plate Recognition cameras, whereas others may choose to enforce manually using local authority enforcement officers. • Would it be necessary to allow exemptions? If so what and why? • How could enforcement work for non-UK vehicles?

Appendix B
List of Stakeholders Consulted

California Air Resources Board (CARB)

Clean Diesel Technologies (CDTi)

Confederation of Passenger Transport (CPT)

Department for Transport (DfT)

Department of Environment, Food and Rural Affairs (Defra)

Eminox

Energy Saving Trust (EST)

Environmental Industries Commission (EIC)

Freight Transport Association (FTA)

Glasgow City Council

HJS Emission Technology

Johnson Matthey

Oxford City Council

Oxfordshire County Council

Proventia

Road Haulage Association (RHA)

Sadler Consultants

Scottish Government

Senate Department for Health, Environment and Consumer Protection in Berlin

Society of Motor Manufacturers and Traders (SMMT)

Transport for London

Transports Metropolitans de Barcelona

Vehicle Certification Agency (VCA)

Vehicle and Operator Services Agency (VOSA)