Key findings

On city region bus fleets and the environment:

- Reductions in regulated pollutants are taking place across all main transport sectors as Euro standards for toxic emissions have taken effect;
- Trend comparisons indicate that on an average per passenger kilometer traveled basis, bus travel appears to have been more polluting in terms of toxic emissions than car travel over the last 10 years;
- Bus travel now appears to be now less polluting that car travel for Particulate matter, and will get increasingly clean as fewer of the oldest buses remain in the fleet. Car travel may still have the advantage for oxides of nitrogen (NO_x) emissions;
- The historic advantage bus travel has over car travel for greenhouse gas emissions appears to be narrowing as smaller and fuel-efficient cars become more popular and car manufacturers react to EC pressure on CO2 emissions;
- The analysis shows the importance of modernising the bus fleet if the bus is to be promoted as a reduced pollution option compared to the car;
- Increasing the passenger loading can only go so far if older buses are kept in the fleet.

On technologies to improve bus fleets environmental performance:

- The most modern conventional diesel buses are hard to beat for reducing pollutants when compared with current alternative technologies;
- In addition, current (business as usual) rates of fleet replacement could substantially reduce emissions from city region bus fleets if the oldest vehicles are replaced with the newest;
- However, there is a continued risk that old buses are operated in areas with dense populations as a significant proportion of old buses remain in the PTE fleet – 25% of buses in PTE areas could be Euro II standard even in 2012;
- In addition, modern conventional diesel buses will not reduce greenhouse gas (GHG) emissions - the least cost-effective way to reduce GHG is to channel investment into conventional diesel buses;
- The key to high levels of GHG emission reduction is high blend and gaseous biofuel and/or diesel-electric hybrid buses;
- However, the comparable cost of biofuel/hybrid buses against conventional diesel technology is currently a considerable barrier and requires a change in one or more of the following: the bus subsidy regime; fuel and vehicle costs; and/or the framework in which the bus sector is regulated and planned;
- Retrofit of pollution abatement equipment to older buses can be very cost effective for reducing key pollutants, and are suitable for vehicles that have considerable useful life remaining;
- Training and then ongoing encouragement of safe and efficient driving can be a very cost effective complementary measure to reduce emissions;
- The most effective way to green PTE/SPT area bus fleets, in terms of absolute costs and emission reduction, is a planned approach with high-blend biofuel and/or hybrid vehicles introduced when the technology is robust and duty rates / BSOG make them commercially attractive, together with a replacement of the oldest diesel buses with their modern low-pollution versions or targeted emission abatement via retrofit technology.

0 SUMMARY

0.1 Study aims

This report has been produced by Transport & Travel Research Ltd (TTR) on behalf of ***pteg*** as part of a study to investigate scenarios and opportunities for reducing emissions of greenhouse gases and toxic pollutants from bus fleets in the PTE areas.

The aims of this study are to provide ***pteg*** with:
- Information on the policy and political drivers for reducing greenhouse gases and toxic pollutants from the bus fleet;
- Information on the strengths and weaknesses of the various emerging technology/fuel options for new buses;
- A set of broadly costed scenarios for renewing bus fleets in the metropolitan areas to a range of environmental standards, with details of the benefits each would bring and the methods by which they could be implemented; and
- An assessment of how possible reforms of the BSOG subsidy regime could impact on the scenarios.

0.2 City region bus fleets and the environment

EU legislation has regulated vehicle emissions through the application of "Euro" standards for vehicle type approval, with limit values for a range of regulated pollutants becoming tighter over the years. Emissions of the various regulated pollutants have fallen by between 20 and 50% on average since 1995. This has contributed to major public health benefits from cleaner air. A further decrease is expected, bringing levels down to 25-50% of the 2000 level by 2020.[1]

However, take up of cleaner engine technologies by vehicle type has proceeded at different speeds, as fleet replacement rates vary across the sectors. Various low emission zone studies have shown the most cost-effective emission reductions can be achieved with Heavy Duty Vehicles, because of their high emission levels per vehicle compared to Light Duty Vehicles. This seems to apply to buses in particular, because of their high average age compared to all other heavy duty vehicles.

Estimates for bus fleet composition up to 2015 predict that around 10% of the UK bus mileage travelled will be done by vehicles of Euro II standard or lower (manufactured in 1996 or earlier).[2] For particulate matter (PM) such vehicles are over 40 times more polluting than the Euro IV equivalent (manufactured from 2005 onwards). The problems of local air quality are exacerbated by the disproportionate amount of pollution produced from the few oldest vehicles.

[1] CAFE - Clean Air For Europe (2005).
[2] Projections from 1999 NAEI road transport emissions inventory, Netcen (1999).

Trend comparisons, based on national statistics,[3] indicate that on average, per passenger kilometre travelled, bus travel appears to have been more polluting in terms of toxic emission than car travel over the last 10 years. This is at odds with the majority of public perception and marketing messages that bus travel is cleaner. Clearly, adding one passenger that previously drove alone to a bus that is already scheduled is going to reduce their contribution to total emissions, but analysis shows there is only so far increasing patronage could help if the fleet profile is based on a high average age.

Estimates are that bus emissions will fall faster than car emissions in the future, so that on average bus travel will become less polluting for PM emissions compared to car (on a passenger km basis). However, bus travel may remain, on average, more polluting for oxides of nitrogen (NO_x) emissions. This analysis shows the importance of modernising the bus fleet if the bus is to be promoted as a reduced pollution option compared to the car, and indicates that increasing the passenger loading can only go so far to achieve emission parity with car travel if older buses are kept in the fleet.

For greenhouse gas (GHG) emissions such as carbon dioxide (CO_2) national figures for bus and car travel, plus analysis of PTE/SPT area specific data in a parallel *pteg* study[4] seems to show the advantage of bus travel over private transport could be narrowing, particularly as new, smaller and/or fuel-efficient car sales increase the proportion of these vehicles in the total car fleet.

0.3 Technologies to improve bus fleets environmental performance

0.3.1 Euro standards role in improving environmental performance

Euro standards describe the emissions criteria that vehicle manufacturers must type- approve their vehicles to in order to supply for general sale in the EU. The first, Euro I vehicles began to be produced for an EC-specific type-approval standard that came into force in 1993. Euro standards apply to all vehicles whatever their technology basis or fuel type.

Each successive Euro standard has reduced the amount of toxic pollutants allowed to be produced, as measured in testing over prescribed drive cycles. The significant impact of this policy on total road transport emissions is highlighted in section 3.1 of this report.

0.3.2 Diesel fuelled vehicles

For Heavy Duty Vehicles (HDV) such as bus, coach and Heavy Goods Vehicles (HGV) the most common technology is a compression ignition engine fuelled by diesel. Combustion in a diesel engine provides one of most

[3] Transport Statistics Great Britain 2007, DfT (2008).
[4] Carbon Footprinting of PTE Policies, Programmes and Projects, AEA E&E for *pteg*.

energy efficient power-plants among all types of internal combustion engines. This high efficiency translates to good fuel economy and low greenhouse gas emissions (compared to petrol). Other positive features include durability, reliability, and fuel safety. The downsides of diesel engines include high noise, low specific power output, NO_x and PM emissions, and relatively high engine cost (compared to petrol).

Conventional diesel vehicles are the standard HDV technology, with the widest range and number of suppliers. Due to the imposition of Euro standards diesel vehicles have increasingly low levels of NO_x and PM. Huge investments in latest engine design by manufacturers have been required to meet Euro standards reliably. In the past there has been a small, and generally temporary, CO_2 penalty from increased fuel consumption in period immediately after a new Euro standard.

The objective of engine manufacturers is to meet increasingly stringent emission limits, while maintaining durability, fuel efficiency and cost effectiveness as far as possible. The adoption of ever more stringent Euro standards has led to improvements in combustion technology, a need for exhaust after-treatment and even the use of additives to help the removal of toxic pollutants.

There will be a small increase in maintenance required for Euro V diesel vehicles that use Selective Catalytic Reduction (SCR) for reducing oxides of nitrogen emissions (NO_x). Exhaust Gas Re-circulation (EGR) is an alternative method for reducing NO_x levels that does not require additives, but is somewhat less efficient than SCR at reducing NO_x.

<u>0.3.3 Retrofit technology for emission abatement</u>

Retrofitting older heavy duty vehicles, such as buses, with exhaust abatement technology can significantly reduce emissions and bring them up to the standard of much newer vehicles that will have benefited from more stringent application of Euro standards at the type approval stage.

To reduce particulate emissions from buses, diesel particulate filters (DPF) are used. When operating effectively DPF can reduce emissions of particulate by 90 - 95%. These are fine mesh filters that collect carbon particles. These devices generally have some means of self-regeneration, such as a fuel-borne catalyst or embedded catalyst within the filter. For DPF to work effectively the vehicle must include in its duties a phase of medium-high speed operation, in order to raise exhaust temperatures and regenerate the filters. Some manufacturers do not recommend fitting their DPF to the very oldest vehicles (pre-Euro and Euro I), whereas others are more flexible. The cost to purchase and fit a DPF is around £4000. DPF require regular maintenance to empty out the ash from combustion of collected particles which could cost about £200 each time, required once or twice a year. Some early DPF increased fuel consumption (by 0.5 - 1%), but newer models have a negligible effect if the filter is maintained properly. There is however a potential issue of increased NO_2 as some evidence links DPF to increased amounts of NO_2 emissions.

Diesel Oxidisation Catalyst (DOC) technology is an alternative option for removing PM emissions. DOCs are effective at removing larger particulate matter, reducing total PM by some 20-50%. The equipment is lower cost (than DPF) at around £1,000 per vehicle. DOCs require minimal maintenance, and are more likely to be suitable (i.e. remain effective) for the very oldest vehicles and those with only low speed duties.

To reduce emissions of NO_x a selective catalytic reduction (SCR) device can be fitted. SCR engines inject urea (ammonia) and water into exhaust gasses, producing nitrogen and water. An SCR can reduce emissions of NO_x by around 50-90%, depending on the duty cycle. SCR is best suited to depot-based vehicles as the system needs topping up with AdBlue (the mix of urea and water used in the SCR system).

Exhaust Gas Re-circulation (EGR) is an alternative approach to reducing NO_x levels, and works by recycling exhaust gases to lower combustion temperatures and emit less NO_x. EGR is somewhat less efficient than SCR at reducing NO_x (at around 40-50%), but does not require additives.

The available retrofit options are not universally favoured (or adopted) by bus operators in the UK. However, the cost-effectiveness of this option for dealing with key regulated pollutants means it should be of considerable interest for a PTE-wide strategy to reduce emissions. Retrofit technology could be very relevant for early low-floor buses that increasingly will be seen as the more polluting sub-section of the bus fleet.

0.3.4 Diesel-electric hybrid

A diesel-electric hybrid is powered by both an internal combustion (diesel) engine and electric motor from battery stored electricity. Regenerative braking is used to recharge the on-board batteries, and because the battery is charged by the operation of the bus no extra charging in the depot is required. As a result a smaller internal combustion engine than normal is required and aided by the electric motor this leads to improved fuel efficiency compared to a conventional vehicle.

Hybrid buses use the same diesel fuel as a conventional bus, and therefore no new infrastructure is required in order to operate a hybrid bus. Maintenance costs for hybrid buses are higher than those for conventional diesel buses due to the additional technology and the need for battery maintenance and replacement in time. Fuel costs are lower due to their fuel efficiency.

Hybrid buses are available in Europe from a small, yet growing, number of manufacturers. Up until this point there has been a limited choice of vehicles produced in small volumes for the UK market. The available technology currently has not had much operational ‘in-use’ testing or experience compared with conventional diesel vehicles. A number of trials to date have experienced reliability problems in diesel-electric hybrid operation.

Revisiting earlier analysis for TfL on the economics of diesel-electric hybrids it can be seen that if diesel prices are high there is a case for operating such vehicles based on fuel savings alone, over a 10-year operating life. This would require reliable and robust diesel-electric hybrids on which to base this long-term financial decision. The current TfL purchasing commitment to hybrids (combined with cost savings due to rising diesel oil prices) should mean much more experience of what is a suitable diesel-electric hybrid, and therefore increase commercial acceptance by some operators in the medium term.

0.3.5 Compressed Natural Gas and Liquefied Natural Gas

Natural gas can be stored as a vehicle fuel either as compressed natural gas (CNG) or liquefied natural gas (LNG). CNG vehicles can be designed to run either solely on gas using dedicated gas engines (mono-fuel), on gas and diesel in the same modified diesel engine (dual-fuel) or by switching between petrol and gas (bi-fuel), with petrol used as a back up fuel and to extend range. Mono-fuel and dual-fuel are the most common designs for heavy duty vehicles such as bus, while bi-fuel designs tend to be used in light duty vehicles and are based on petrol engines.

Natural gas is made up of a mix of propane and butane and is derived from natural gas fields or from oil refining and is therefore not a renewable fuel. Life cycle CO_2 emissions are approximately the same as for diesel (perhaps 10-15% lower) but NO_2 emissions are significantly lower (80 per cent lower) and particulate matter is virtually non-existent. These natural advantages are being eroded as diesel engine exhaust abatement technology improves in response to successive Euro standards, although the very best gas engines can still outperform the best diesel engines on most relevant emissions. Noise levels are lower than for equivalent diesel engines.

Gas vehicles can be purchased new, or converted from existing diesel vehicles to run as dual-fuel. The best emissions performance tends to comes from dedicated gas engines. Fuel storage tanks on the vehicle add weight can reduce the overall payload for certain types of vehicle (such as buses). The additional fuel storage requirements and specialist engine modifications/design mean higher costs for a new vehicle. Maintenance costs for gas buses have tended to be higher than for conventional diesel buses due to higher parts costs and increased maintenance requirements, although there is some experience of this being dealt with through negotiation at the procurement stage. Fuel costs are lower so it is possible for high-mileage fleets to benefit financially from this fuel, particularly when covering high mileages. The best financial case for CNG tends to be for use in long-distance freight haulage operations in the UK (for quickest payback of the capital costs).

There have been some trials of CNG buses in the UK. Early trials did not produce convincing results, with initial problems over reliability and maintenance costs. The variable quality/specification of gas used may have been a factor. In addition, the configuration of the Fuel Duty Rebate (FDR) and its replacement, Bus Service Operators' Grant (BSOG), meant that fuel costs were higher overall than for diesel vehicles. Experience with the technology has improved performance, but there are few CNG buses operating in the UK at this time.

0.3.6 Biomethane

Biomethane is the term used for upgraded and cleaned biogas (the raw gas) produced from anaerobic digestion of organic matter, or decomposition in land-fill sites. Biomethane is chemically very similar to natural gas, and therefore can be stored in the same way and used in the same vehicles. Biomethane is available in compressed and liquid forms (as per natural gas).The use of biomethane in vehicles has many of the same benefits, and barriers, as using natural gas.

A major advantage compared to natural gas (and many other road transport fuels) is that biomethane is a renewable fuel produced from waste materials and therefore the life cycle carbon emissions are significantly reduced. Using biomethane in vehicles can give a reduction in life-cycle CO_2 emissions of around 80-90% compared to conventional diesel. If the waste material is animal manure, that would otherwise decompose and release methane into the atmosphere, then capturing this via the AD process and using it as a fuel actually produces a negative CO_2 balance.

0.3.7 Biodiesel

Biodiesel is produced from the vegetable oils from crops such as rapeseed or soy, or can be reclaimed from recycled waste cooking oil. Biodiesel can be blended with conventional diesel at varying proportions. At low-blends diesel vehicles can be refuelled in the same way as conventional diesel vehicles and therefore major new infrastructure is not required, although care is required during storage of the fuel to prevent water absorption.

Low-blend fuels containing 5% biodiesel (B5) are widely available and can generally be used in the same way as conventional diesel. Higher blends (e.g. B10, 20, 30, 50 and B100) are available to varying specifications, but their suitability depends on the vehicle requirements. Reliable use will depend on the specification (and blend limit) the vehicle manufacturer has defined as acceptable.

Biodiesel has been known to break down deposits of residue in the fuel lines where mineral diesel has been used. As a result, fuel filters may initially need changing due to clogging with particulates if a quick transition to high-blend biodiesel is made.

Life cycle CO_2 emissions vary depending on the source of the biodiesel. If land use change is not considered and assuming today's production methods, 100% biodiesel from rapeseed and sunflower oil produce 45%-65% lower greenhouse gas emissions than normal diesel. Lower blend biodiesel produces proportionately lower GHG savings.

0.3.8 Bioethanol

Bioethanol is produced from the fermentation of plant-based materials, such as corn, wheat and sugar cane.

Bioethanol can be used in compression ignition engines, suitable for heavy duty vehicles such as buses, designed or modified to handle the different characteristics of ethanol as a vehicle fuel. Bioethanol as a bus fuel is generally 95% biofuel with the remainder comprised of ignition improvement additives. Etamax-D and Greenergy E95 are examples of fuel produced for bioethanol specific compression ignition engines such as those found in Scania buses. The most experience of bus fleet operation in Europe is found in Sweden, using Scania-manufactured vehicles.

For high-blend bioethanol special transport, storage and refuelling infrastructure is needed, because ethanol can corrode equipment designed for diesel or petrol. Ethanol and water can dissolve into one another, degrading the properties of the fuel, which requires precautions in fuel storage and handling.

The fuel costs per litre of bioethanol are slightly lower then diesel (<5%) but fuel consumption on a volumetric basis is higher than gasoline by about 50-60% for pure ethanol (about 40% for E85) due to the lower energy density. For this reason, fuel consumption of bioethanol buses will tend to be higher than their diesel counterparts.

Estimates of the GHG savings of bioethanol vary widely, mainly depending on the type of feedstock and manufacturing process. Depending on the production method and source, the best-performing bioethanol gives a 70% carbon dioxide reduction, with UK-sourced bioethanol providing around a 25 to 50% reduction, from either wheat or the more effective sugar beet.

0.3.9 Hydrogen fuel cell

Hydrogen is produced by the electrolysis of water or by the breakdown of a hydrocarbon source (e.g. natural gas, fossil fuels or ethanol). In some cases it is also produced as an industrial by-product.

When used as a fuel the only by-product of hydrogen combustion is water, leading to zero tailpipe emissions. Life cycle CO_2 emissions vary depending on the source of electricity used to produce the fuel. Where renewable electricity is used, the life cycle emissions can be lower.

Production of hydrogen-fuelled vehicles has been limited to a small number of demonstration fuel cell projects made by a few vehicle manufacturers. Currently such vehicles can cost up to 10-20 times more to produce than their conventional fuelled equivalents (e.g. £1m+ per bus). At the present stage of development the cost of the vehicles and associated refuelling infrastructure is extremely high.

Therefore hydrogen fuel cells and hydrogen combustion engines are considered to still be at a prototype stage, with only small-scale demonstrations having been carried out (e.g. in London). While useful, these should be viewed as steps in a longer-term process. It is very unlikely that this technology will become commercially attractive to bus operators within the 10-year time horizon of this study.

0.3.10 Driver training for fuel efficiency

Driver behaviour can significantly affect fuel consumption and therefore is a potential non-technology route to achieving reduced emissions (of both regulated and GHG). HGV operators who implement fuel management programmes (of which vehicle and driver performance monitoring and incentive schemes are component elements) achieve a minimum of 5% fuel savings within the first year.[5] Actual savings depend on the exact nature of the fuel management programme or the individual initiative implemented.

Much work has been done in the field of fuel efficiency in the HGV industry, but it has been much more slowly adopted in the public transport industry. Information from the major bus operators suggests they wish to do more in this area and there is certainly much potential for improvement and cost/emissions savings.

0.3.11 Conclusions on current and emerging technologies / fuels

For new vehicle purchasing decisions, the latest Euro standard conventional diesel buses are very attractive for reducing the environmental impact of PM and $NO_{x,}$ given their reliability, tested design and bus operators existing experience in refuelling, operation and maintenance of such vehicles. As new vehicles they are a very cost effective option.

Retrofitting older vehicles with exhaust after-treatment for NO_x, PM or a combination of both (with a dual system) is extremely cost effective, but has not been attractive to bus operators in the current regulatory regime where there are few commercial benefits to reducing pollution further than the business as usual trends.

A number of technology/fuel options are available that can reduce emission levels to lower than current Euro standards and more significantly reduce GHG emissions. Low-blend biofuel such 5% biodiesel (B5) are becoming standard and on a national basis will contribute to a noticeable reduction in GHG emissions from road transport. However, the key to more significant

[5] SAFED for HGVs - A Guide to Safe and Fuel Efficient Driving for HGVs. DfT. (2006)

levels of GHG emission reduction from bus fleets is in the use medium to high-blend and gaseous biofuels and/or hybrid drive-trains. Biodiesel at a high-blend could deliver the GHG benefits of renewable fuels at a lower additional cost, as engine design and refuelling infrastructure are quite similar to standard diesel. For the same reason diesel-electric hybrid technology has the practical benefit of using a standard diesel fuel, and potentially in the future medium to high-blend biodiesel.

In the UK the key sustained take-up of high-blend biofuel will be an effective reform to BSOG and a favourable fuel duty differential on biofuel for buses beyond 2010, in order to overcome the price disincentive to bus operators.

A complementary option for reducing fuel use (and associated emissions) is for bus operators to introduce fuel management systems and safe/efficient driving training and incentive schemes for bus drivers.

Table 0.1 below summarises the current status of the technologies and fuels for use in bus fleets, together with their current advantages and drawbacks.[6] The biofuel options are for high-blend fuels (>10% by volume).

It should be acknowledged that experience of alternative technologies and fuels to date has included problems with performance and reliability. The maintenance cost of a new technology, introduced in small numbers, is generally higher than the existing and accepted option. Capital costs for supply and storage of alternative fuels tend to fall more heavily on the initial users, making the upfront costs needed to use biofuel much less likely to be offset by the potential for lower fuel costs. The current system of BSOG has up until now actively discouraged take-up of alternatives to diesel fuel, and any capital investment in order to reduce fuel consumption (e.g. diesel-electric hybrids).

The use of diesel-electric hybrids, high-blend bioethanol and biodiesel or gaseous fuels such as biomethane will require an investment in one or more of the following: depot fuelling equipment; training and maintenance regimes; and more expensive vehicles. The kinds of issues that will need to be addressed in order to make cleaner, low carbon technologies and fuels more viable include: improving vehicle reliability; reducing absolute costs; and/or enabling the factoring the value of saved emissions into purchase and/or operating costs.

One aim of this study is to attempt to forecast forward when these issues might be addressed. If a sufficient number of current policy drivers, support mechanisms and initiatives ensure momentum behind low emission technology/fuel options then a potential pathway to cleaner fleets over the next 10 years could initially be based on diesel-electric hybrids, followed by high-blend and gaseous biofuels and ultimately biofuel-electric hybrids. This study makes some predictions about when low emission technologies and fuels could be commercially attractive to bus companies, and uses this as a

[6] Update of a summary table from EST Transport Energy 'The Route to Cleaner Buses'(2003)

basis for some of the future scenarios for greening PTE/SPT fleets, which are described in chapter 4.

Table 0.1: Summary of current technologies and fuels

Fuel / vehicle type	Pros	Cons
Diesel	Standard technology and therefore of widest availability and number of vehicle and fuel suppliers; increasingly low levels of air pollutants (PM and NO_x) from advancing engine design and exhaust treatments; current BSOG arrangements refund 80% of duty on diesel used making it cost-effective compared to alternative fuels with lower duty levels.	New Euro standards sometimes herald slight rise in fuel consumption; some increase in maintenance required for Euro V SCR engines.
Natural gas (CNG or LNG)	Slightly lower CO_2 emissions compared to diesel; low levels of air pollutants; low levels of engine noise; low fuel duty compared to diesel. Vehicles quite widely available in mainland Europe.	Currently limited public refuelling infrastructures; dedicated refuelling infrastructure more costly than diesel; loss of some load space due to weight of gas tanks; vehicles are more expensive to buy and maintain than diesel vehicles; reliability/cost issues in early UK bus trials.
Biomethane (CBG or LBG)	Considerably lower CO_2 emissions. Remainder as per natural gas.	Currently not available via the natural gas grid, so requires dedicated transport as well as refuelling (unless depot located with production site).
Bioethanol	Lower CO_2 emissions compared to diesel; low levels of air pollutants; low fuel duty compared to diesel.	Dedicated refuelling infrastructure slightly more costly than diesel; fuel efficiency considerably lower at high-blends. Choice of fuel source can impact on sustainability.
Liquefied petroleum gas (LPG)	CO_2 emission similar to diesel, generally low levels of air pollutants; lower engine noise; low fuel duty compared to diesel	Limited but expanding public refuelling infrastructures (1200); loss of some load space due to weight of gas tanks; vehicles are more expensive to buy than diesel vehicles, but maintenance cost now largely similar to diesel; reliability/cost issues in early UK bus trials
Diesel-electric hybrid	Lower CO_2 and other pollutants compared to equivalent diesel; requires only diesel fuel; better fuel economy.	Vehicles are more expensive than diesel counterparts and require more specialist maintenance; earlier stage of development compared to diesel mean reliability yet to reach that level.
Biodiesel	Lower CO_2 and reduction in PM; low blends need no modification needed to engine.	Low blends provide more limited benefits (although on a national scale these are significant); higher blends often not acceptable under manufacturers warranty; slight increase in NOx emissions compared to ULSD. Choice of fuel source can impact on sustainability.
Battery electric	Zero emissions at point of use; low cost fuel; silent operation.	Batteries and vehicles have tended to be more expensive than diesel vehicles; pollution still created (at power station) unless created from renewable sources; vehicle size currently limited; range can be limited between charges; battery durability can be limited.
Hydrogen fuel cell	Zero emissions at point of use; low noise operation. Potential for low CO_2 emissions if based on renewable sources.	Experimental/pilot stages of technology mean extremely high purchase and operation costs; requires specialised/ dedicated refuelling infrastructure.
Exhaust abatement technology (retrofit)		
Diesel Particulate Filter (DPF)	Highly effective at reduction particulate matter including ultra-fine particles (by up to 95%); can quality vehicle for reduced pollution certificate (RPC) and lower Vehicle Excise Duty (VED).	Choice of DPF needs matching to age of vehicle, and duty cycle of vehicle to ensure optimum operation; annual/bi-annual maintenance required; early or poorly maintained DPF increased fuel consumption; may be some evidence of increased NO_2 production.
Diesel Oxidisation Catalyst (DOC)	Effective at removing larger particulate matters (20-50%); Lower cost (than DPF); more likely to be suitable for very oldest vehicles and any duty cycle; minimal maintenance.	Cannot reach potential emission reduction of DPF.
Exhaust Gas Recirculation (EGR)	Has potential to reduce NO_x emissions by 40 – 50%, depending on duty cycle; can be retrofitted to a range of HDV; no	Cannot reach potential emission reduction of SCR.

	maintenance.	
Selective Catalytic Reduction (SCR)	Has potential to reduce NO_x emissions by 30 – 70%, depending on duty cycle; can be retrofitted to a range of HDV.	Requires topping up with urea when refuelling (approx 5% by volume). Will become the norm for modern Euro V HDV that use SCR. Retrofit to older vehicles only benefits NO_x levels.

0.4 PTE policy context

PTE responsibilities and powers to influence commercial bus services in their area have been limited. Regulations from the recent Local Transport Act 2008 will enhance the existing mechanisms of VPA, SQP and QC to provide more effective methods of improving network, timetable and vehicle quality through the co-ordinating role of the PTE (or Transport Authority in non-Metropolitan areas).

DfT has extended Traffic Commissioner powers to enable actions to be taken on grounds of improving air quality via Traffic Regulation Conditions (TRC). TRC have been taken up in Bath and more recently and extensively in Norwich, as the basis for a Low Emission Zone.

Overall, PTEs have been hindered in their efforts to introduce cleaner, low-carbon vehicles, as bus operators understandably resist any increase in costs or risk to their operations (from non-conventional vehicle technology). The arrangements for Bus Service Operators' Grant (BSOG), previously called Fuel Duty Rebate, only hindered the economic case further against investing in fuel-efficient vehicles or renewable fuels. Support for low-carbon buses through changes to BSOG was announced in the November 2008 pre-budget report.

Overall, there are significant policy steps to encourage low emission and low carbon vehicles in the UK, but until very recently there have been some sector-specific barriers to their introduction for bus services in the deregulated environment outside London.

0.5 Fleet improvement scenarios, impact and costs

A range of scenarios for the renewal of the Metropolitan area bus fleets was determined, based on the review of policy drivers, policy tools, current/emerging initiatives and trends in technology/fuels.

Scenarios were produced based on a combination of different vehicle replacement rates and varying ambition (and appetite) for alternative technology/fuels. The technology/fuel component of each scenario is based on different proportions of current conventional combined with fuel-efficiency technology (i.e. hybrids) and GHG reducing technologies (hybrid plus biofuel powered vehicles).

Three study years were chosen, from the current situation (2007/8) to the future years of 2012/13 and 2015/16. The future years are the business as usual (BAU) outcomes expected if rates of fleet renewal continue at current levels of 5.5% p.a. A more optimistic 2012/13 BAU scenario was generated based on a higher than current fleet replacement rate of 7.5% p.a. The business as usual (BAU) estimates provide the baseline years against which ‘do-something’ scenarios were generated and then measured. Five do-something 2012/13 scenarios were generated and four 2015/16 scenarios. The scenarios resulting from the combination of replacement rate and ambition for alternative fuels/technologies are illustrated in Table 0.2 below.

Table 0.2: Summary of fleet renewal scenarios

		Level of ambition and Fleet renewal policy			
Year		**BAU**	**1. Low**	**2. Medium**	**3. High**
2012/13	**Fuel / Technology mix**	a) Conventional diesel	a) Fuel efficiency	a) Fuel efficiency	a) Fuel efficiency
				b) Fuel efficiency & biofuels	b) Fuel efficiency & biofuels
2015/16	**Fuel/ technology mix**	b) Conventional diesel	b) Fuel efficiency	c) Fuel efficiency & biofuels	c) Fuel efficiency & biofuels
					d) Conventional diesel
Fleet replacement rate (p.a.)		a) 5.5% current b) 7.5% optimistic	5.5%	10%	16.5%

In an effort to make the scenarios more realistic the numbers of vehicles that could be ‘replaced’ with more fuel efficient or renewable (bio) fuelled vehicles was carefully estimated based on the actual composition of various PTE bus fleets and the selected fleet replacement rates. The availability of future technologies at a reliability and cost likely to enable commercial take up was built into the estimates. For example it was predicted that diesel-electric hybrids do not start entering the future PTE fleets until after 2012, and high-blend biofuel vehicles a year or two later than that. This means that the 2012/13 year scenarios include somewhat limited numbers of non-conventional vehicles, which limits their impacts, but is a more realistic forecast.

For each of the scenarios developed, a broad assessment of the costs and environmental impacts has been carried out. To estimate the impacts of the scenarios actual sample fleet data from the PTE/SPT areas has been used as inputs to a spreadsheet tool. This tool has been used to assess for each scenario the environmental impacts relative to a future business as usual baseline. Vehicle replacement numbers have been used in tandem with data gathered during the background stages to estimate broad capital costs of each scenario. In this manner, estimates were made of the amounts of regulated and GHG emissions for each scenario and of investment costs in each PTE/SPT area.

Figures 0.1 and 0.2 below show the total NO_x and PM tailpipe emissions for each scenario. Emission estimates have been compiled separately for each PTE area, but presented together in these figures to show the impact of the scenarios across the total PTE/SPT area bus fleet.

To aid understanding, the percentage decrease between the current 2007/08 situation (5.5% replacement rate) and the 2012/13 baseline business as usual (BAU) scenario is annotated in orange. This shows a 29% reduction for NO_x and a 49% reduction for PM. These reductions are due to anticipated improvements in average bus fleet emissions as a result of progression through the Euro standards. The green annotation then shows the percentage decrease in emissions for each of the 2012/13 scenarios compared to the current BAU 2012/13 scenario. The blue annotation highlights the percentage decrease in emissions for each of the 2015/16 scenarios compared to the BAU 2015/16 scenario.

Figure 0.1: NO_x emissions by scenario

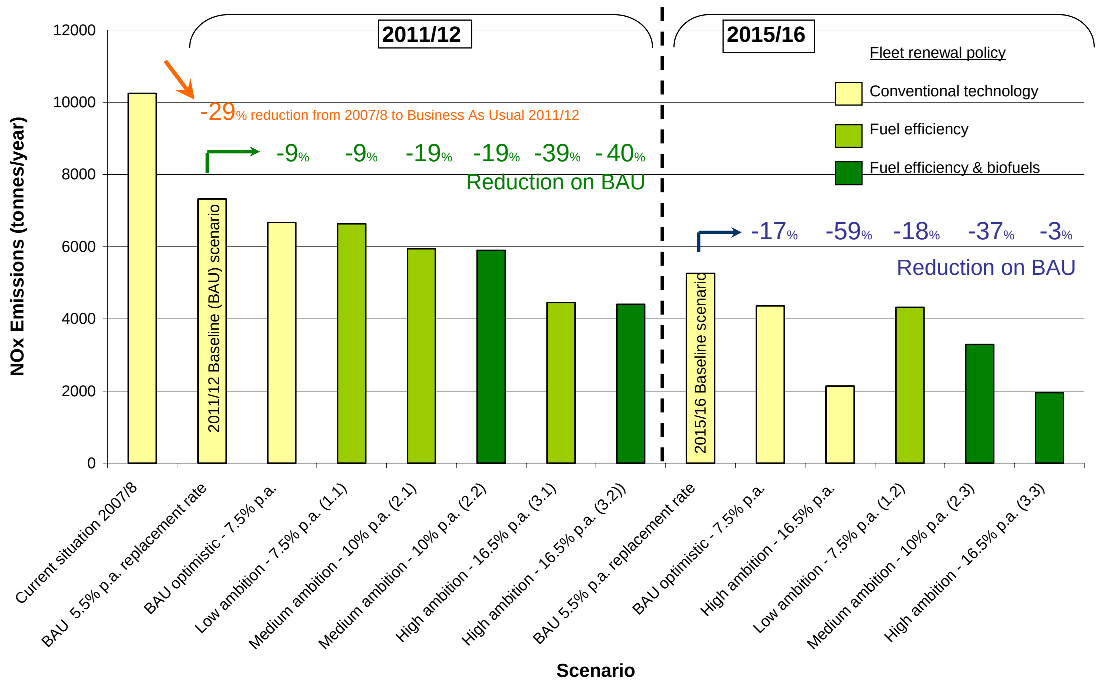
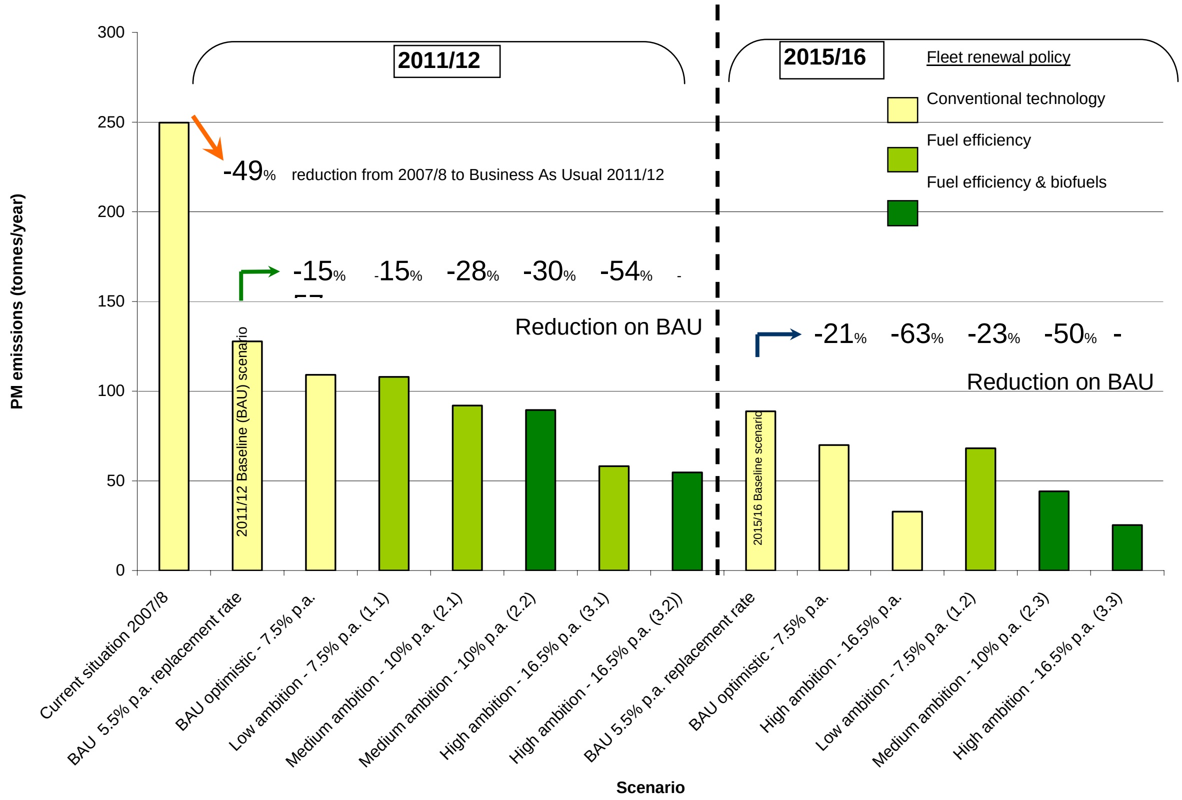


Figure 0.2: PM emissions by scenario



The analysis of absolute emission reductions shows that for toxic pollutants the most important tool to reduce emissions is to ensure (and hopefully accelerate) the vehicle replacement rates to remove the oldest, most polluting vehicles from the bus fleet. Older vehicles are disproportionately polluting, and even taking the national (average) view some very polluting vehicles are predicted to remain in the fleet for some years to come.

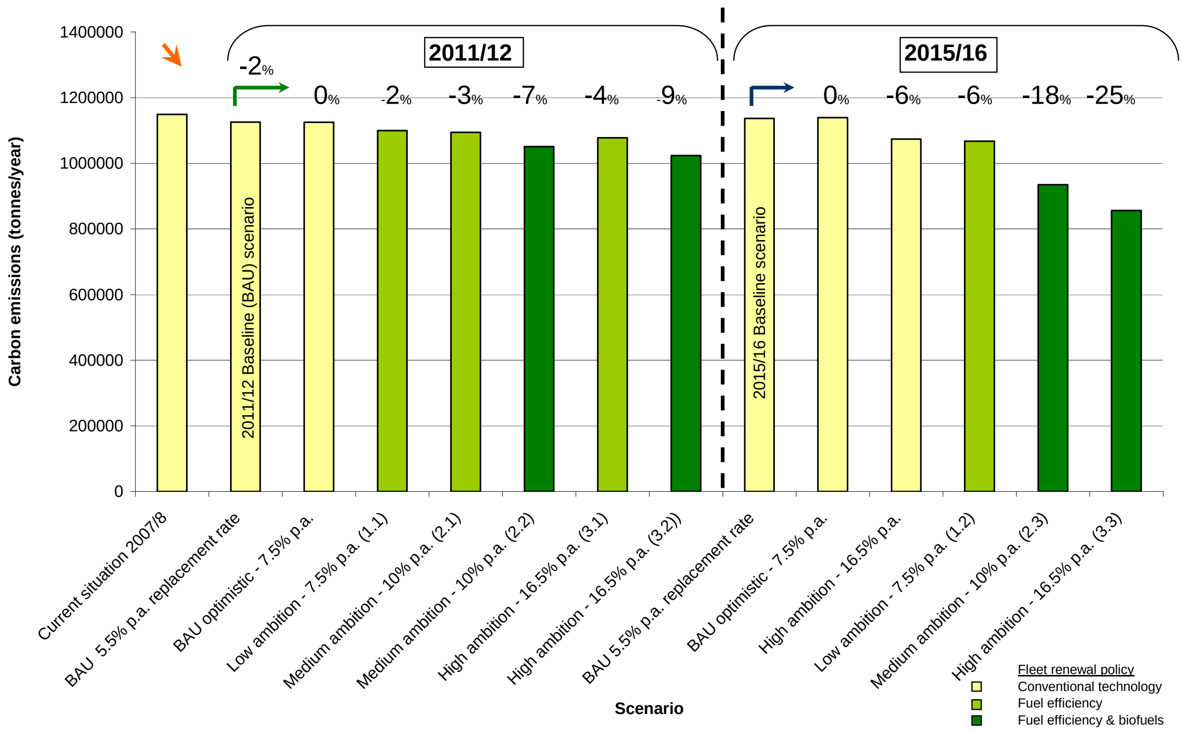
The analysis suggests that new technologies (diesel-electric hybrid and renewable fuels) can reduce toxic emissions further, but conventional diesel vehicles will become increasingly ‘clean’ and difficult to beat on regulated pollutant emissions. The latest conventional diesel vehicles are predicted to achieve nearly as much of a reduction in regulated pollutants as if some of this investment in new vehicles was allocated to diesel-electric and biofuel vehicles. Therefore, realising the additional benefits of alternative technologies and fuels can only be done by deploying significant numbers, rather than small scale demonstrations on single routes.

The study has also undertaken a similar analysis of scenarios based on the life-cycle emissions of producing, distributing and using a particular fuel in a given technology. The estimates use comparatively conservative figures for the potential benefits of renewable fuels. Overall, the analysis emphasises that, in contrast to the toxic emissions, fleet renewal with solely conventional diesel vehicles does not have an impact on life-cycle carbon emissions and is not a cost-effective way to achieve reductions in greenhouse gases. If vehicle kilometres travelled and driver behaviour remains the same, then carbon reduction is only possible with greater fuel efficiency and/or renewable fuels.

The analysis illustrates that the largest reductions cannot be realised until further into the future (2015/16). This is largely because more wide-spread commercial take-up of diesel-electric hybrids and medium to high-blend biofuel are not anticipated in PTE/SPT areas before 2012.

The more ambitious scenarios in 2015/16 assume the when new vehicles are purchased they include reasonable numbers of hybrid and high-blend biofuel vehicles (around 60%) to complement the conventional diesel vehicles, and that about half of the diesel vehicles operate with B20 (20% biodiesel) blend. With such scenarios the analysis shows it could be possible to achieve significant GHG reductions (of 18 - 25%), noting this is based on rather conservative estimation figures.

Figure 0.3: Life-cycle carbon emissions by scenario



It is important to understand the levels of investment that would be required to achieve a given emission reduction scenario. The study has therefore built on the cost-assessment of various technology/fuel options presented in Chapter 3 to estimate a total capital cost for each scenario in each PTE/SPT area. It is clear that increasing the fleet replacement rates from the current 5.5% to the scenarios representing 7.5%, 10% or 16.5% would have a very significant cost, whatever the technologies chosen in the mix of new vehicles. Based on current experience, biofuel and hybrid vehicles are estimated to require additional capital investment costs in the future compared to conventional diesel technology. Biomethane is estimated towards the upper end of the range of capital costs, diesel-electric hybrids around the middle and biodiesel towards the lower end of the range.

A complementary action for reducing fuel use (and associated emissions) whatever the technology used is for bus fleets to introduce fuel management and safe/efficient driving training and incentive schemes for bus drivers. In addition retrofit with DPF, and potentially SCR/EGR, could play a significant role in cleaning up older vehicles which otherwise are serviceable and Disability Discrimination Act (DDA) compliant.

From the analysis undertaken the best overall strategy to ensure a significant reduction in regulated and GHG pollutants is to share new vehicle purchases between latest conventional diesel technology, diesel-electric hybrid and biofuel vehicles in order to achieve a reasonable scale of reduction while combining the relative cost-effectiveness each technology brings to these different emissions.

However, as noted earlier in this chapter the additional cost of hybrid and some types of high-blend biofuel buses over conventional diesel operation is a considerable barrier to overcome and requires a change in one or more of the following: the bus subsidy regime; fuel and vehicle costs; and the framework in which the bus sector outside London is regulated.

0.6 Conclusions

The study has considered what mechanisms would be important to realising the scenarios proposed for greening PTE bus fleets. The various scenarios modelled in this study are made up of two components: a fleet replacement rate and a policy for certain technology/fuel characteristics (supporting diesel fuel efficiency and biofuels, or just diesel efficiency).

It is possible that the ‘low-ambition’ scenarios with replacement rates of 7.5% may be achieved by operators alone, under influence of external factors such as:

- operators increasing their fleet replacement rates in response to the upcoming DDA compliance dates;
- the historically high price of diesel (and in parallel an improving economic and reliability case for hybrids).

In order that high-blend biofuels and fuel-efficient vehicles can be considered in a strategy for greening PTE fleets in more than pilot/demonstration numbers, effective changes to the relationship between fuel duty and BSOG are required. An announcement on incentives for low-carbon buses was made in the November 2009 pre-budget report, with details to follow, but the current favourable duty differential of 20ppl for biofuels is due to be reviewed in 2009/10.

There is an argument for supporting demonstration of biofuel technologies in the UK now that there are some large bus fleets operating in a few mainland European cities using dedicated bioethanol, biodiesel and biomethane vehicles. Demonstrations can be useful to help overcome some understandably negative perceptions held by UK bus operators based on earlier vehicle trials, which will otherwise be a barrier to introducing many of the GHG reducing technologies into PTE bus fleets.

Changes to the current arrangements for the organisation of bus services in PTE areas are required in order to achieve a shift sufficient to reach the medium and high-ambition scenarios proposed in this study. These are now dependent on regulations for SQP and QC derived from the recent Local Transport Act. It is hoped that the stability and removal of damaging competitive practices can enable long-term investment plan to be to properly costed, decisions made and then implemented. Work has begun at some PTEs on the opportunities that SQP and QC would provide, and this information and experience should be shared as a matter of priority as a basis for a strategy to green bus fleets.