SEStran

Alternative Fuels for Buses

Issue 1 - Review and Recommendations for Alternative Fuel Use within the SEStran Area

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February 2008

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1 Summary

TAS partnership is responsible to SEStran for a report on their bus fleet focusing on alternative fuels, vehicle standards, fares and bus stop infrastructure. Arup were subcontracted by TAS primarily to undertake the investigation on alternative fuels.

The work started with a focus meeting to identify what SEStran's priorities were for alternative fuels. This identified that local tailpipe emissions were the highest priority closely followed by Green House Gases (GHGs). In terms of usage, it was concluded that the work should focus on inner city drive cycles.

Historically fuel research has been focused towards fossil based solutions with an aim to reduce tailpipe emissions locally and in particular Particulate Matter (PM) emitted from diesel engines. Over recent history, we have seen significant legislation introduced that has reduced emissions across the fuelling spectrum, and it can now be argued that diesel vehicles with after treatment are approximately as clean as alternative fuels, especially if the vehicle adheres to EEV regulations.

With this background in mind, renewable alternative fuels, electricity derived fuels and vehicle technology in forms such as hybridisation were compared, to understand what effects they would have on a market increasingly focused on GHGs.

The results are difficult to quantify due to variations in measurement across different tests, continuing development of a robust understanding of real GHG emissions on a well to wheel (WTW) basis, and uncertainty in production processes and cropping for alternative fuels moving forward.

The results suggest that the short to medium term strategy should be focused on hybridisation of the fleet, increased renewal rate of buses to remove those that do not meet the Euro III specifications, and retrofitting of Euro III buses where after treatment is not to the highest specification. Alternative fuels in the form of Generation 1 biodiesel and ethanol could also be considered in low blends, to develop a technical understanding of their issues.

In the long term it is recommended that there is an investigation into using electricity as an alternative fuel through the uptake of a trolley bus network (possibly hybridised) on high density routes linked to the tram network. Outside the trolley bus network, a study should be undertaken on the duty cycle for the routes to understand whether hybrid powertrains or high blend Generation 2 biodiesel or ethanol should be considered, and it is envisaged that the result will be a mix of hybrid and one fuel selected for the fleet.

In order to take this study forward, we would recommend a thorough transport plan, and detailed assessment of the bus fleet is performed to understand how the recommendations can be implemented.

2 Introduction

The TAS Partnership Ltd. commissioned Arup to undertake a portion of their submission to SEStran regarding bus initiatives. The focus of the work discussed in this document relates to issue 1 of the full submission as follows: -

Issue 1

- Review existing bus fuel use and policies within the SEStran area.
- Review the potential for the use of alternative fuels, identifying practical supply and economic/environment issues
- Review the use of similar schemes to use alternative fuels in the UK and elsewhere
- Identify how greater use of alternative fuels could best be developed in the SEStran area.

Addressing the task above can lead to a very broad and unfocused report, and to focus the discussion, a review of SEStran operators and local government was undertaken, to ensure that the key issues are addressed.

3 Review of Considerations for SEStran Area

The key to developing an effective policy for SEStran area is to establish and prioritise the issues to be considered for the alternative fuel study. These priorities have guided our decision-making through the task, and enabled conclusions to be drawn.

3.1 Pollutant Emissions

The primary issue is to understand which pollutants we should focus on with the following being the main consideration:

3.1.1 Emissions From Tailpipes

The gases NOx, PM, CO and HC are associated with tailpipe local emission concerns. The major ones that require focus are NOx and PM. Local emissions are controlled through air quality legislation and measured at sites to ensure conformance. The lifetime of measured pollutants is short and measured in days / weeks, resulting primarily in local effects.

Oxides of Nitrogen (NOx) – Formed from the combustion process, NO combines with oxygen in the atmosphere to produce NO_2. High levels of NO_2 are linked to respiratory problems and an increased response to allergens in humans, and NO_x also contributes to smog and acid rain.

Fine Particle Matter (PM) – This contributes to human health issues with particular effect on respiratory problems, especially in individuals with existing conditions. The main issue is $PM_{10,}$ which are particles that are small enough to pass into the human respiratory system.

Carbon Monoxide (CO) - Reduces the blood's oxygen carrying capacity, resulting in reduced oxygen to key organs. In extreme conditions exposure can be fatal. In small doses the main concern is for people suffering from heart conditions.

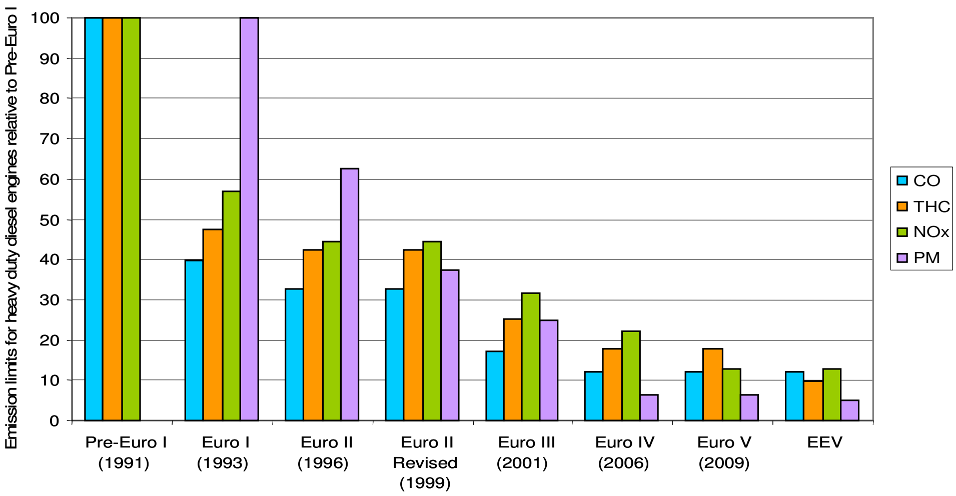
Total Hydrocarbons (THC) – Hydrocarbons contribute to ground level ozone formation and result in respiratory system issues. Some hydrocarbons are carcinogenic.

It is important to note that, for a given vehicle technology and efficiency, the generation of all of these gases is in direct proportion to the amount of fuel used by a vehicle.

EU limits for heavy duty vehicles (g/kWh)

Tier	Date	CO	THC	NOx	PM
Pre-Euro I	April 1991	12.3	2.6	15.8	-
Euro I	October 1993	4.9	1.23	9.0	0.4
Euro II	October 1996	4.0	1.1	7.0	0.25
Euro II Revised	October 1999	4.0	1.1	7.0	0.15
Euro III	October 2001	2.1	0.66	5.0	0.10
Euro IV	October 2006	1.5	0.46	3.5	0.02
Euro V	October 2009	1.5	0.46	2.0	0.02
EEV	Not yet agreed	1.5	0.25	2.0	0.02

Graphic representation of table results



The above graph shows what has been achieved with a continuous and long term forward plan for tailpipe emissions, with the projected level of tailpipe emissions being approximately 10% of pre Euro 1 levels.

3.1.2 Emission Regulations for Green House Gases

CO_2 which is not controlled in the same way as the pollutants listed above, is associated with greenhouse gases, and is therefore a global rather than local issue. It has an effect over a long period of time (150 years for CO_2 and 12 years for methane). As a result, the pollutants travel large distances from where they are emitted, affecting the climate of other countries. Global agreements are aimed at regulating these pollutants with national governments setting their own reduction targets and policies. The Kyoto Protocol is an international agreement between the world's countries designed to address global warming at an international level.

UK Government's climate change bill sets legally binding targets of a 60% reduction by 2050 and a 26-32% reduction by 2020.

The driver for fleet operators has been the link to fuel efficiency and therefore commercial benefit to operators through lower fuel costs. The measure by which government has an influence on this is currently through tax on fuel, although there is significant debate about whether the BSOG will be changed to focus more attention on reducing this pollutant.

3.2 Energy Security

Energy security issues can be minimised by reducing the dependency on any particular fuel. This can be achieved in two ways.

- Widening the choice of vehicle fuels
- Enabling the use of multiple base fuels by using energy carriers such as electricity or hydrogen on the vehicle, and transferring the energy production from the transport sector to the generating sector.

3.3 Vehicle Life Cycle Costs

The life cost of a vehicle is in 3 phases: manufacture, use and disposal. Typically the 'in use' phase will account for 85% of a vehicle's energy consumption throughout its life cycle (including the manufacture and disposal of the vehicle).This "in use" phase is the current focus of the operator, as it is represents the amount of fuel consumed by the vehicle. As vehicles become more complex, their manufacture and disposal energy will gain in importance. If we also start to reduce the age of the fleet to use newer vehicles and thereby encourage greater patronage the use phase then reduces, and therefore the overall balance changes further.

3.4 Vehicle Duty and Drive Cycle

The vehicle's duty cycle is important to this investigation, as it will significantly influence the choice of fuel type and powertrain technology. Essentially there are 3 main types of duty cycle

- City Centre (high stop-start low speed)
- Extra Urban (slightly higher speed, fewer stops, and a more constant speed)
- Inter City (few stops, and high average speed)

The key parameters that are considered when choosing commercial vehicles tend to be operating costs and the fuel consumption of the vehicle. This is directly linked to green house gas emissions as described above, but is crucially linked to the Tank to Wheel (TTW) phase of fuel use.

3.5 Fuel Life Cycle Costs

As we move to alternative fuels, the efficiency of the Well to Tank (WTT) phase becomes as important as the Tank to Wheel (TTW) phase. The extreme example of this is when a vehicle is run on hydrogen or electricity; at the point of use (TTW) emissions are zero for local pollutants and carbon.

3.6 Survey of SEStran Area Priorities for Fuel

It should be noted that the above issues will strongly influence the outcome of the study, and that focusing on tailpipe emissions can result in a different outcome to a focus on energy security. In order for this work to be specific to SEStran area, a survey of operators and local authorities was conducted ahead of detailed analysis.

3.6.1 Survey Results

The responses from the survey are summarised as follows:

- Air quality locally is the key concern as legislation is in place which specifically targets local authorities to resolve any hot spot problems.
- The majority chose green house gas emissions second priority and wanted to understand the effect of focusing on local emissions
- Energy security may become a rising issue over time, but ideas on how to reduce risk are only of general interest.

A separation of aims appeared when considering the question of how the fuels were evaluated.

Local authority response has appeared to favour the wider aspects of the analysis with the following:

- The choice of how to look at fuel emissions on Well to Wheel (WTW) basis will ensure that the overall effects of energy and greenhouse gases are taken into account; but it should be noted that this will break the link between fuel grants and vehicle efficiency. This should be considered in any implementation project.
- In addition to WTW, a focus on vehicle whole life cycle is preferred to solely looking at the “in-use” phase.

Bus operator responses tended to take the contrary view, which can probably be explained by current funding practice.

- Tank to Wheel (TTW) will look at the efficiency of the vehicle in operation.
- Operators are not interested in construction or end of life disposal costs. It can be noted however, that there is a close link between reducing energy consumption and increasing vehicle price for fleet vehicles (where ‘fashion’ does not play such an important part in decision making). Vehicle technology will increase in complexity, correspondingly affecting price, which must be amortised over the life of the vehicle.

3.6.2 Conclusions from Survey

For the purpose of this task, we have focused on local emissions for city driving as priority. Given the focus from Government, the report also offers information on the wider GHG emissions issues.

4 Review of the Potential for Alternative Fuel Use

To assess the relative merits of different fuels and technologies, it is necessary to consider the full "well to wheel" implications.

- The "well to tank" phase: - creating, growing or extracting the feedstock; the industrial processes and transport required to turn feedstock to fuel.
- The "tank to wheel" phase: - the in-vehicle process and technologies that change the fuel to motive power.

4.1 Summary of Considered Fuels

This section describes the main fuels, their advantages and disadvantages, their emissions and overall environmental performance.

4.1.1 Diesel Fuel (Business as Usual)

The Business as Usual (BaU) fuel feedstock is crude oil converted to diesel by fractional distillation. This is an understood and optimised process with an easily defined Well To Tank (WTT) value. The carbon emissions during the WTT phase have in the past largely been ignored when considering the efficiency of fuels, and vehicles, but should be considered when comparing alternative non-fossil fuels.

4.1.2 Ethanol Fuel

Ethanol is a liquid fuel produced from corn, grains or other agricultural products; this classes the fuel as renewable. When the fuel is manufactured from waste biomass, the potential benefits in reduced CO_2 are significant, whereas conversion of crops displacing food or resulting in deforestation are both controversial, and can provide significant CO_2 increases on a Well to Wheel basis.

Heavy duty vehicles generally use compression ignition (Diesel cycle) engines, in which the fuel is injected directly into the combustion chamber. Fuel grades vary, with common mixes being E100, E95, E90, E85 blended with gasoline. The fuel is lower in energy density than oil derived diesel.

In Europe, Scania have supplied over 400 ethanol buses to Stockholm SL, and this is a significant development. Major research is ongoing into ethanol, and it may yet emerge as the fuel of choice should Generation 2 biofuel process technologies become feasible in high volume.

4.1.3 Methanol Fuel

Methanol is mostly derived from natural gas, but can be produced from coal and biomass, resulting in a wide range of Well to Wheel values for CO_2.

In heavy duty applications, methanol is used in compression ignition engines fuelled with M100 and M85 plus a lubricant additive. Methanol has a small (5%) reduction in fuel economy compared with Diesel.

Emissions of NOx and PM are significantly lower than Euro III diesel engines, and comparable with Euro IV.

Running costs for engines using methanol are significantly higher than those of diesel engines, and this, combined with a lack of fuelling infrastructure in the UK makes the outlook bleak for methanol heavy duty applications.

4.1.4 Compressed Natural Gas (CNG)

This gaseous fuel is pressurised natural gas, and thus a very simple hydrocarbon (mainly Methane - CH_4). CNG is a fossil fuel, and therefore, as with all fossil fuels, reserves are finite.

This fuel has been used significantly in stationary applications due to its clean burning characteristics. The biggest issue for CNG is its low energy density, resulting in reduced range or increased fuel storage capacity requirements.

The majority of engine manufacturers producing heavy duty diesel engines also produce a gas engine equivalent. There are two types of combustion for these engines:

- Spark ignited with the same technology as used in light duty applications
- Dual fuel compression ignition where a mixture of air and gas is ignited by a small injection of diesel fuel

The engines are significantly lower in NOx and PM compared with Euro III diesel engines but comparable with Euro IV.

CNG has a lower energy density than diesel, and produces less power for an equivalent engine size. This will lead to a requirement for larger engines. However, when combined with hybrid technology, the engine size can be reduced again as it is running constant load.

CNG vehicles cost significantly more than an equivalent diesel engine due to the cost of engine modifications and additional fuel tanks. The weight of the vehicle is increased leading to potential reduction in payload.

Maintenance and service depots will require adaptation to include the CNG equipment.

4.1.5 Biomethane

Biomethane is fuel derived from waste. Through anaerobic digestion, CO_2 and methane are produced, and after processing and compressing the methane, we have the equivalent of CNG (or LNG if liquefied) but from a renewable source.

The properties and technologies will be the same for this gas as its fossil equivalent. Biomethane as a waste product is considered one of the ultimate carbon negative fuels. The methane given off by the waste goes to atmosphere unless collected and used, and has 23 times the GHG potential of the CO_2 given off by the same amount of burnt fuel.

Legislation is currently being discussed to allow Biomethane to be channelled into the gas stream and gain ‘green’ status in the same way that it is possible to buy green electricity. With this change in status, we may see an emergence of niche product applications for Biomethane such as bus operations, waste vehicles, or certain long distance haulage firms.

Predictions for the volume of waste available now and in the future are very variable, but even high estimates would result in only a small percentage of total transport fuel demand being met by this fuel. Combined with additional costs for vehicles, and specialist servicing there are limited applications, but one of these could potentially be the bus fleet given its inherent low noise burn characteristics and clean image.

The same engine and vehicle comments apply as those for CNG.

4.1.6 Liquefied Natural Gas (LNG)

LNG is primarily composed of methane as with CNG. Natural gas becomes a liquid at -162ºC, and has over twice the storage density of CNG, for typical storage pressures.

The fuel burns with the same efficiency and tailpipe emissions as CNG, but is generally used on large trucks and some large transit buses. Combustion technology is also essentially the same although there are recent developments in direct injection. Fuel tanks usually replace existing diesel installations in a chassis.

The engine fuel economy is generally 10-15% lower than diesel equivalent, with tailpipe emissions similar to Euro IV diesels. Vehicle tanks will vent gas over time as the liquid warms up, and this needs to be considered in fuel economy as well as safety in service depots.

Vehicle system costs are circa 50% higher than diesel equivalents, because of the need to accommodate the low temperature tank and equipment.

4.1.7 Liquefied Petroleum Gas (LPG)

LPG is essentially propane (with limited levels of ethane and butane) under mild pressure turning it to liquid. The fuel is a fossil fuel. As the liquid is drawn from the tank it changes state back to gas.

The combustion technology is spark ignition, which does not lend itself to practical conversion of diesel engines since it would require the addition of an ignition system and gas metering equipment. Some recent developments have looked at direct injection of a combination of diesel and LPG.

4.1.8 Hydrogen via Fuel Cell or ICE

Hydrogen fuel can be consumed to produce energy in either a converted internal combustion engine or a fuel cell. The most widely used fuel cell for automotive applications is the Proton Exchange Membrane type (PEM).

Hydrogen fuel is currently mostly produced from steam reforming and partial oxidation of natural gas (a fossil fuel) which therefore has a significant well to wheel energy consumption compared with hydrogen produced from renewable energy. This is now available as technology for onboard conversion, but work is also underway on fuel cells that can operate on directly injected methanol into the fuel cell.

In heavy duty applications, Ballard is leading the way with their PEM fuel cell using direct hydrogen fuel tanks with a 205kW cell in a Daimler Benz ‘NEBUS’ (CUTE Programme) The current trend is to apply fuel cells to ‘series’ hybrid buses where the fuel cell can operate at a constant load to recharge the batteries, with drive directly from the batteries.

The significant advantage of Fuel Cell Vehicles (FCVs) is their zero emission performance at point of use. The only other technology providing this is electric vehicles. The Well to Wheel energy consumption will always be higher than an equivalent electric vehicle given that energy has to be used to generate the hydrogen which is then used to power the fuel cell. The range of an FCV is significantly better than a battery only solution due to the energy density and volume.

4.1.9 Biodiesel

Biodiesel is the generic name for a variety of diesel fuels based around methyl esters of vegetable oil or fats. Frequently in Europe this has originated from rape seed oil but other sources are corn, cottonseed, peanut, sunflower, canola and palm oil.

The fuel closely resembles conventional diesel but with a slightly higher cetane number. It is frequently blended with 20% Low Sulphur Diesel (B20), and although there is a high percentage of fossil based fuel in the mix it is still classed as an alternative fuel.

The fuel is essentially sulphur free and reduces hydrocarbons and CO compared with diesel. NOx is slightly higher.

When used in vehicles, care needs to be taken with the material of the fuel system to ensure compatibility of rubber based components, but with modern polymers this is less of an issue. The fuel does not perform as well as diesel at low temperatures due to clouding, and therefore may need fuel heaters in cold conditions.

One of the significant concerns with Generation 1 Biodiesel is that the term can cover a wide range of substances and difficulties are being seen with certain blends even at low Biodiesel content.

4.1.10 Synthetic Diesel

Synthetic diesel is also now available manufactured from natural gas, which allows a significant opportunity for remote gas fields to create a high quality product which is inherently clean due to its simple chemical composition. This process is known as Gas to Liquids through the Fischer-Tropsch process. The fuels can be used as 100% synthetic, or blended with petroleum diesel to provide an improved lower tailpipe emitting product compared to conventional diesel.

Synthetic diesel can also be manufactured from biomass to liquid processing, which becomes a renewable fuel.

The advantages of this Generation 2 synthetic diesel, is that it is an accurately controlled process which produces a ‘clean’ product with little variation. The vehicle manufacturers will be able to develop engines robustly when they have these designed fuels, and problems currently being seen with Generation 1 Biodiesel should be reduced.

4.1.11 Dimethyl Ether (DME)

This is generally produced from Natural Gas, but can also be produced from crude oil, coal, crop residues, oil, wood or straw. It has excellent emissions characteristics with low sulphur and NOx but has significantly lower energy content compared with diesel. The fuel is a gas at atmospheric temperatures, and is stored in a similar pressure and tanks to LPG. One of the issues with the fuel is its low lubricity, and therefore additives are required to make the fuel usable in compression ignition engines.

4.1.12 Hybrid Vehicles (Electric and Mechanical)

A Hybrid Electric Vehicle (HEV) is one which uses at least two sources of motive energy (electrical and mechanical or mechanical and mechanical) to propel the vehicle. Typical vehicles have an electrical storage device such as battery or ultra capacitor in combination with a mechanical device, such as a diesel engine.

Two main types of HEV are available.

- **Parallel hybrid:** a vehicle which can be driven by just one of the two power sources or both together.
- **Series hybrid:** in which mechanical power is used to charge an energy store. The wheels are directly driven by the energy from the store.

The advantages of a hybrid are

- Optimised IC engine operation, minimising transient loads and varying engine speed range, thereby enabling engine performance to be optimised.
- Reduced engine size due to the ‘constant’ load required
- Regenerative braking can be utilised to varying degrees dependent on the energy store.

The choice of HEV type is dependent on the duty cycle for the vehicle. The fundamental difference between the vehicles is that with a parallel configuration there are less conversions of the energy from one state to another resulting in theoretically improved efficiency. In practice, the drive cycle will determine the best configuration; and for heavy duty vehicle applications with very high stop-start demands, the series hybrid has proved to be the option of choice by current manufacturers.

Fuel economy over a city cycle is improved by over 30% against a conventional diesel engine, and significant reductions in tailpipe emissions can also be achieved due, essentially, to the reduced volume of fuel used.

With improvements in battery technology, we may see the emergence of buses with higher battery capacity, having limited capability as electric vehicles and some capability to ‘plug in’ to the grid for opportunity charging. This development could offer further tailpipe emissions improvements, and zero tailpipe emissions in some critical operating areas within the network (see below).

An alternative to the electric hybrid vehicle is that of the mechanical flywheel hybrid coupled via a Constant Variable Transmission (CVT). These devices offer very short energy storage times, but have a large advantage in that they can recoup significantly higher amounts of engine braking. On a bus drive cycle such as the 159 London cycle, with continuous stop-start throughout, preliminary analysis would suggest that this technology offers a significant improvement over the electric hybrid, without the concerns over life cycle issues and battery technology. Historically, several systems have been tested, and the masses of the system have been relatively high. New systems are being developed which run the flywheel at very high speeds in vacuum. This significantly reduces mass for the system and package space.

4.1.13 Electric (Battery or Grid)

The strong advantage of the pure electric vehicle is its ability to provide zero tailpipe emissions at point of use. The electric vehicle transfers its CO_2 emissions to the power generating sector, but in global warming terms, a shift of energy from the transport sector is considered the best way of reducing overall greenhouse gas emissions as it allows the large generating plants to decarbonise to a level that is not achievable onboard a vehicle, and offers further potential to use the waste heat. An additional benefit is the improvement to energy security that this provides, as the electricity can be derived from renewables as well as a variety of fossil fuels.

Clearly the electric solution is the most desirable to achieve reduced tail pipe emissions, but in practice on heavy duty applications it has significant issues to overcome.

Operation ‘off grid’ via charging a battery system is not practical for large buses with significant duty cycle running for many hours in a day. The required energy density is not yet available in a battery (and unlikely in the medium term), so battery operated vehicles have limited use in small minibus operations working on short local networks, where inner city emissions are critical.

Current technology is focused on developing lithium-ion for vehicle applications. Nickel metal hydride is the battery of choice in current vehicles where high energy density is more important than cost.

The only practical electric solution for high capacity buses in a city environment is the trolley bus. The vehicles have zero tailpipe emissions at point of use working on grid energy mix. Although a number of systems were in place in the 30’s and 40’s, the use of trolleybuses went into decline as diesel engines became more powerful. A number of cities in Europe continued to use trolley buses and there is now growing enthusiasm right across Europe, with new designs drawing on bus technology to provide increased passenger capacity.

Trolley buses are now available with auxiliary power units, providing “off-line” capability of up to 10kms, thereby resolving their inherent limitation.

Modern systems now use higher voltages (typically 750v DC), allowing lighter, neater and cheaper overhead lines, with the pick-ups controlled from the driver’s cab. Single and double articulations up to 18m in length provide capacity of up to 180 passengers.

4.1.14 The Emission Benefits of ‘Add-on Technology’ to Diesel Powertrains

To put the above fuel options into context, we should also consider the effect of applying emission reduction technology to Diesel vehicles.

Since 1999 all diesel fuel in the UK has been Ultra Low Sulphur Diesel with a sulphur content of 50ppm. This change alone has resulted in reductions of approx 40% on particulates, but more importantly it has enabled diesel after-treatment technology to be applied to reduce emissions still further.

4.1.14.1 DPF

The fitment of a Diesel Particulate filter (DPF) in the exhaust stream is a highly effective method of reducing emissions of fine particles PM_{10}. The technology has to be selected to meet specific drive cycles and, for city usage, trap heaters or catalysts may be required. Use of particulate filters can reduce PM by up to 95% with a catalysed (Diesel Oxidation Catalyst) DPF also reducing CO and HC by circa 80%. The fitment will increase fuel consumptions marginally with a corresponding increase in CO_2 emissions.

4.1.14.2 SCR

Selective Catalytic Reduction (SCR) uses ammonia or urea injected into the exhaust to reduce NOx by between 30 and 70% but this is highly dependent on duty cycle. SCR cannot be retrofitted.

4.1.14.3 EGR

Exhaust Gas Recirculation (EGR) is similar to SCR in targeting NOx reduction and can be considered as a retrofit item. The technology adds regulated amounts of exhaust gas to enter the intake manifold and reduce the temperature of combustion with a benefit of between 40% and 50% reduction on NOx. The technology is frequently used in conjunction with a DPF and offers a good quality solution at a reasonable cost. Technology is quite costly, and requires regular maintenance.

4.2 Review of Fuel over Well to Wheel

Local tailpipe emissions are relatively easy to compare across fuel types, have legislation in place, and over the last 10 years there has been considerable success in reducing these from buses. Looking forward, the main consideration will be global warming and the ability of the fuel to reduce GHGs over the life cycle for which legislation will emerge in the medium term. The legislation is difficult to formulate, but will probably be based on the Climate Change Bill for the EU stating a reduction target of 26-32% carbon by 2020 and 60% reduction by 2050.

The Renewable Transport Fuels Obligation set a target of 2% biofuel mix by 2005 rising to 5,75% by 2010. Problems with this legislation already exist, with the 2005 actual achieved value at 1% and the estimate for 2010 currently at 4.2%. In addition to this, there is much discussion on the carbon saving of Generation 1 biofuel when considering the full life cycle analysis of the fuel, and in particular, significant change of land use.

With developing new legislation, we need to consider what alternatives to conventional diesel are most suitable for the bus fleet. The most appropriate methodology for this analysis is to consider a full Well To Wheel approach and compare this with Diesel BaU, whilst being mindful of any significant tailpipe emission differences between the fuels.

The second significant consideration will be whether the fuel is derived from finite fossil reserves or from renewable feedstock (biofuel) or energy sources. Note that in several cases, technologies and infrastructure are being progressed for a fuel that is currently from a fossil feedstock but which is expected to move to a more renewable feedstock in the future. The main energy sources / carriers and technologies fitting this description are:

- Hydrogen from reforming natural gas which can be substituted by renewable energy in the UK energy mix.
- CNG and LNG technology which will use the same technology as biomethane from waste
- Electricity from the UK grid mix which has the potential for increasing its renewable content

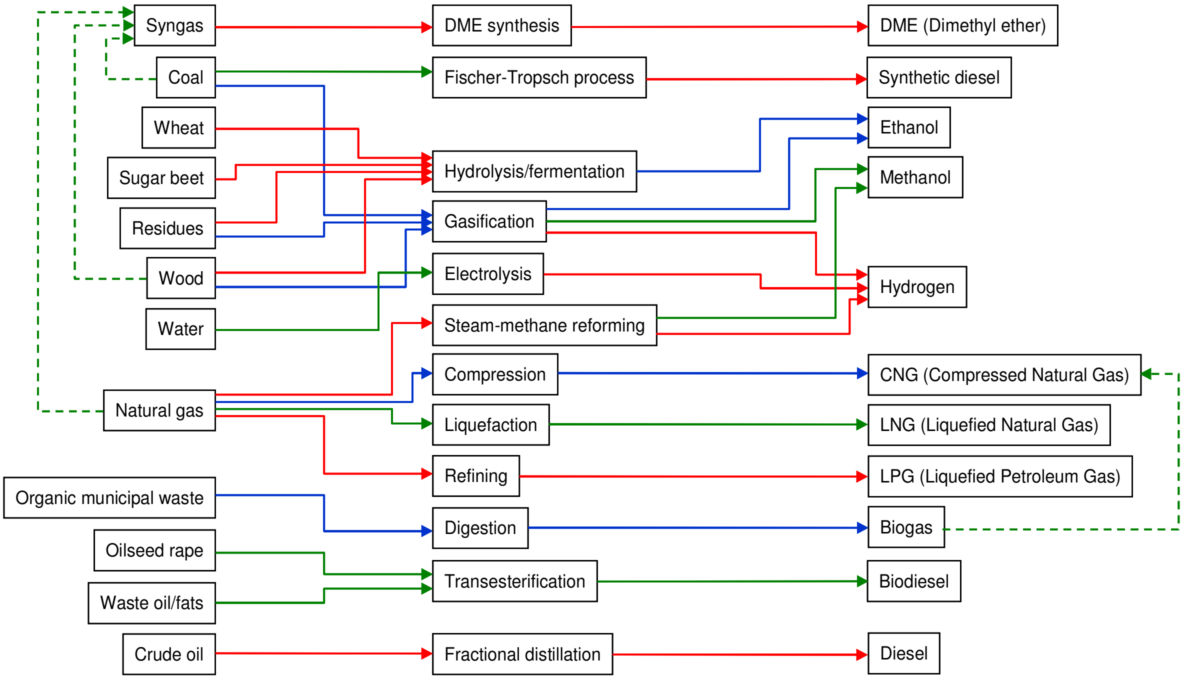
4.2.1 Feedstock Options

The chart below illustrates a small proportion of the multiple feedstocks available to produce transport fuels. It focuses on the main feedstocks and energy carriers that could be considered for alternative fuelled busses.

The complexity of choice involved just on feedstock input, and the diversity of fuel output is clear. A single feedstock can be transformed into multiple fuels and vice versa.

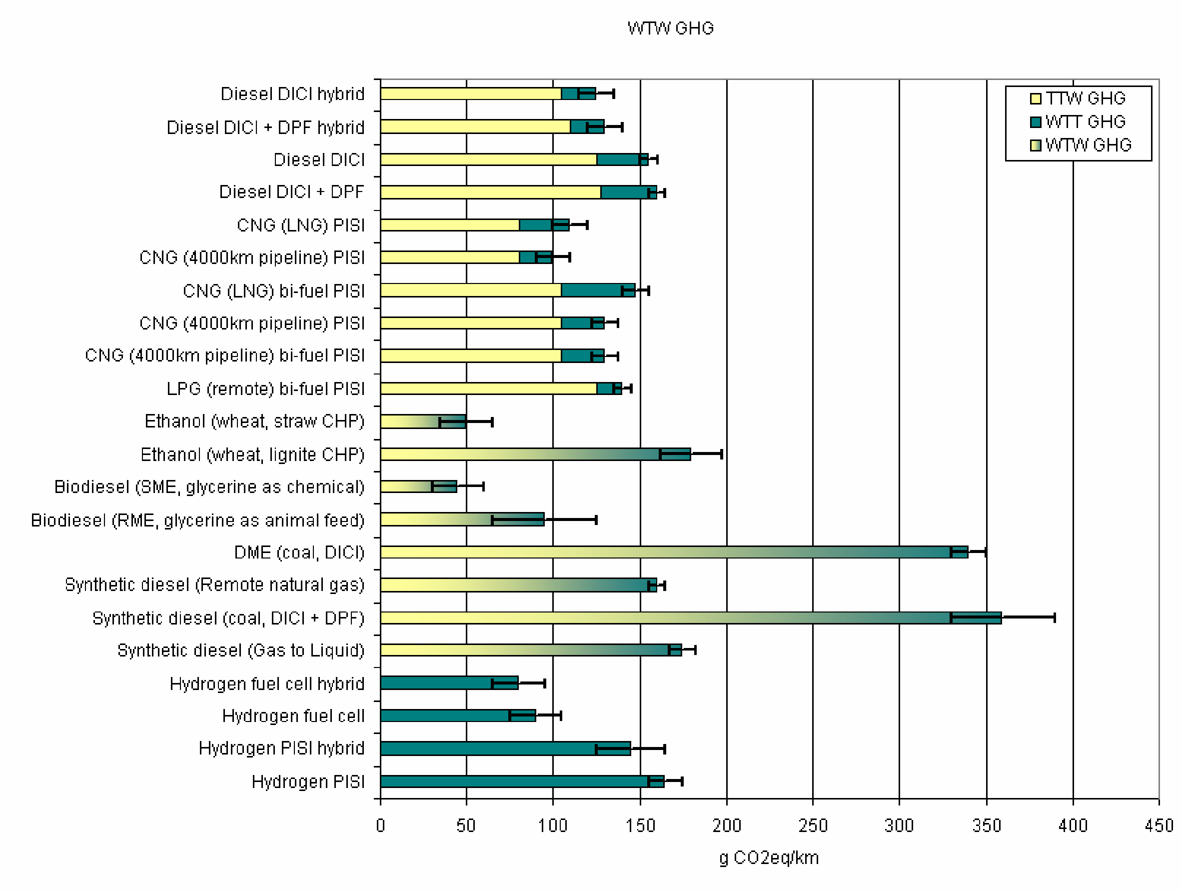
Legislation on tailpipe emissions has now made almost all fuels in principle equal (as a % of emissions at Euro IV compared with allowable emissions for Euro I). Accepting this statement makes tailpipe emissions reduce in importance over time compared with GHGs.

In considering costs, market trends must be monitored, as it is extremely likely that the technology, servicing and infrastructure for the favoured fuels will reduce in cost following their widespread adoption.



4.2.2 Well to Wheel

The Well to Wheel data presented here is from a report prepared by CONCAWE. The work is based around a medium class car and the NEDC drive cycle, and as such has limitations when comparing it to the mass of a bus and passengers over a city cycle such as the London based '159' cycle. In particular, when we look at the opportunity for using hybrid technology (in this case the series hybrid technology most appropriate for a bus) the figures need to be considered carefully, as the bus cycle is particularly biased towards stop-start and low speed where hybrid technology / regenerative braking offers most advantage.



Key findings to note from this graph are

- Fossil based alternative fuels offer little benefit compared with BaU diesel
- In some cases, fossil based alternative fuel has significantly higher GHGs than BaU, and the justification for the fuel is focused on using resources that would be uneconomic without the conversion process.
- Biofuel such as ethanol can offer significant WTW savings from certain feedstocks even at Generation 1 processes. However the savings are dependent upon feedstock and production process, and the same biofuel can offer a worse GHG emission than BaU. (Compare the ethanol from wheat, straw CHP (Combined Heat and Power) and from wheat, lignite CHP*)*
- There is significant variance even within the same feedstock and final fuel – note the tolerance bar.
- The value of hybrid technology looks low on this automotive drive cycle. However when looking at an inner city bus drive cycle (159) and mass, the advantages of hybridisation are much higher. (see later graph on bus performance)
- There is no comparison in the above chart for electrification (trolley bus or battery vehicle) because the car market has no medium sized battery powered vehicle in current production.
- The above data assumes that there is no change of land use, which is a significant concern with Generation 1 biofuel.
- The chart shows GHG benefit from using 100% fuel, but the likely future will be some high blends with the majority of biodiesel and bioethanol running at low blend due to availability relative to total demand.

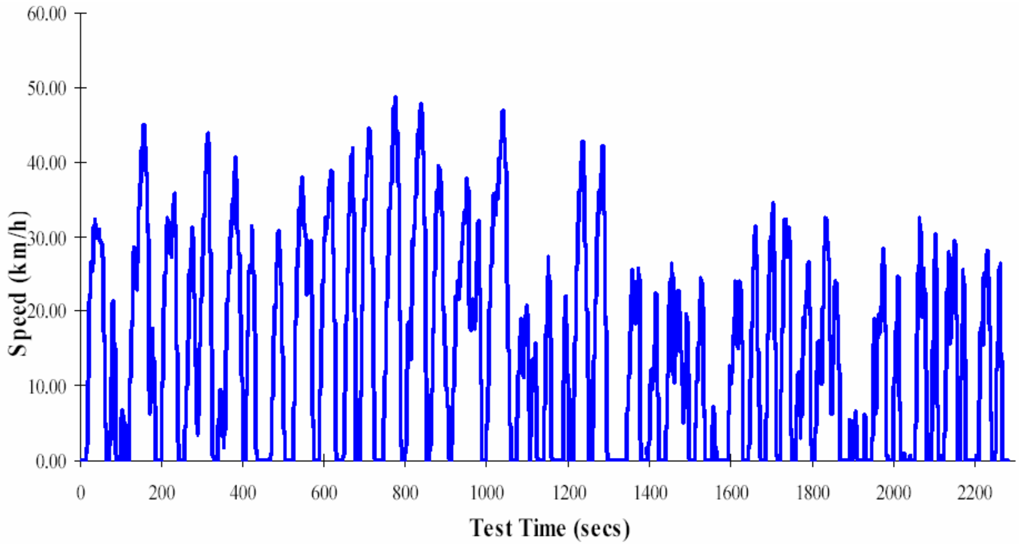
It is clear that biofuel when produced from the right feedstock, correct land use and low energy, production feasible process, can offer significant GHG benefits over BaU, and must therefore be considered as the most favourable fuel for the mid to long term future. The above highlighted points make the decision difficult at this time for the following reasons:

- Legislation and methodology is still under development to control the supply of biofuel. Currently the emissions of some biofuels over their lifetime are significantly higher than BaU due primarily to the change of land use and the use of only a part of the feedstock (Generation 1). This will change in the short term but is having a significant detrimental effect on the market's perception of biofuel.
- Significant research money is flowing into biofuel and in particular the production processes to break down fibre structures under the banner of 'Generation 2' biofuel. Should these processes be successful in mass production for a particular feedstock and end energy carrier, then this will influence the fuel choice more significantly than the absolute value of GHG's saved compared with BaU.
- Land take, available land (food production v energy), water supply, and suitable climate, will also influence volume of supply. The analysis in this area has been undertaken by various bodies to understand what is feasible in terms of total energy available from fuel crops compared with the energy required within the transport sector overall. In broad terms, most studies have been based at approx 25% of EU land including set aside, and all exports. Using Generation 1 feedstock and processes this could provide between 5 and 10% of our transport fuel requirements. If we look at the same area of land under a projected Generation 2 scenario, using lignocellulose crops we could conceivably see a total switch to biofuel with a low projection of transport fuel demand. This analysis alone offers considerable difficulty in trying to identify the best route forward. The fuels available under this scenario could be methanol, ethanol and hydrogen, with significant money still feeding into research into hydrogen and more recently ethanol.

4.3 Tailpipe Performance of Alternative Fuels compared with Baseline Diesel

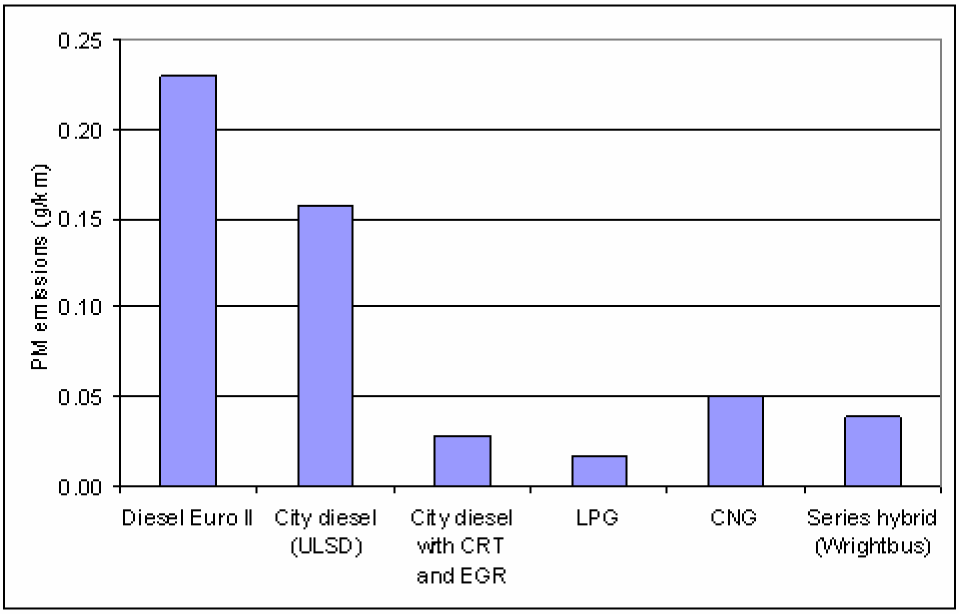
The tailpipe emission regulations are based on engine emissions on a test bed as shown under section 3.1.1. To understand tailpipe emissions we need a real world comparison over a drive cycle for a bus of similar mass, payload and duty cycle. This data is not readily available and therefore a comparison is difficult.

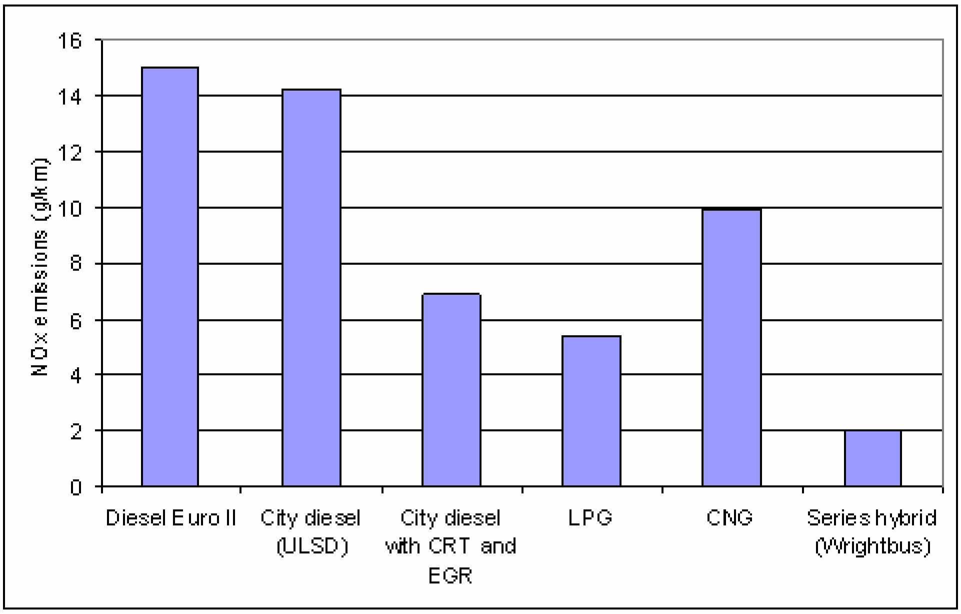
Work is ongoing at Millbrook Proving Ground on behalf of TfL specifically to rectify this situation, and it is hoped that this will be published later this year. TfL have been working on rationalising their alternative fuels decision for several years, and the start of this work was to develop an agreed drive cycle. This is now accepted as the 159 route shown below, and TfL's continuing work uses this to compare all future fuels and alternative technologies.



Earlier work by Millbrook evaluated a series of fuel options and compared these with a series hybrid bus. The results shown below indicate that in tailpipe emission PM is similar across for alternative fuels, hybrid and diesel after treatment, with a significant advantage for hybrid on the NOx figures.

The results compare fossil-based alternative fuels to the relatively new technology of a series-hybrid bus, and a diesel where after treatment technology has been applied to the engine. It can be seen that decisions on alternative fuels should not be made solely on tailpipe emissions, as there is little real world performance difference when compared with the Euro 1 emission baseline.

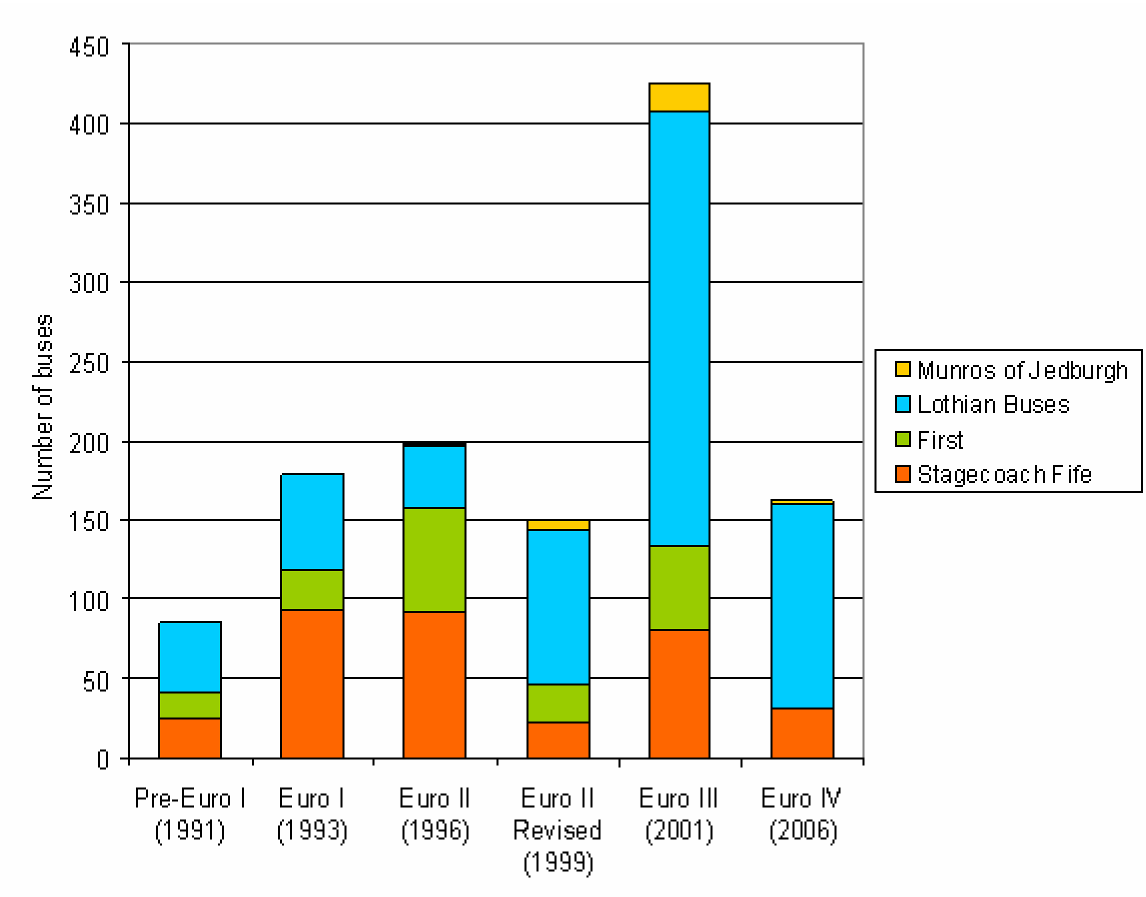




4.3.1 Baseline SEStran Fleet

With tailpipe emissions being the priority, it is important to consider the status of the current bus fleet operating in the SEStran area. The graph below indicates the spread of emission levels across the fleet for the main operators in the region.

Existing Fleet Position



From this data we can conclude:

- A high proportion of vehicles are available at Euro III or better. These vehicles run on ULSD, and dependent on their after treatment technology, they could offer approximately the same tailpipe emissions as fossil based alternative fuels
- At Euro IV, the emissions of particulates will be the same level for all fossil alternative fuels.
- Within the timescale for introducing a new alternative fuel technology it is likely that the Pre-Euro 1 and Euro 1 vehicles will be replaced by Euro V or optional EEV vehicles resulting in an even cleaner overall fleet with respect to tailpipe emissions.

4.4 The Suppliers of Technology – Bus Engine Manufacturers

All the manufacturers of bus engines in Europe are currently producing engines which are compliant with Euro 4, and in some cases Euro 5, which does not come into force until 2009.

When compared to Euro 1 standards of 15 years ago, engines which comply with Euro 5 emit 74% less nitrous oxides and 94% fewer particulates.

Daf

Using SCR technology, Daf is already producing and selling a range of engines which meet Euro 5, and with the addition of a particulate filter they believe they will be able to meet EEV legislation.

Iveco (Irisbus)

Iveco supplies diesel and bio-diesel engines which meet current (Euro 4) legislation. They also produce CNG engines which meet EEV legislation

MAN

Man is currently producing Euro 4 compliant engines using EGR only. By adding a particulate filter as a production option they can achieve Euro 5 and EEV. This removes over 95% of particulates.

Mercedes Benz

Mercedes Benz bus engines utilise SCR to meet Euro 4 legislation. This should also enable them to meet Euro 5 and EEV.

Scania

Scania is using EGR to deliver Euro 4 legislation; this will also be used for Euro 5. Scania also manufactures engines which run on Ethanol.

Volvo

Volvo bus engines are currently Euro 4 compliant, and will meet Euro 5 using SCR technology. Volvo also offers Biogas options, and is developing its own hybrid technology.

5 Review of Similar Alternative Fuel Schemes

The appendices provide a more detailed data on relevant trials identified for buses in UK, wider Europe and USA. The key findings and directions for these trials are summarised below.

5.1 UK

The two councils in UK that have made significant effort in terms of focusing on tailpipe emissions and more recently on GHGs are Liverpool and London (TfL). Liverpool can be seen as pioneering in their adoption and trial of several vehicle types, with London taking on the task in recent times. The main focus has been to reduce tailpipe emissions through increased use of diesel after-treatment, either retrofit or original equipment, followed by an increased uptake of hybridisation of vehicles where appropriate and beneficial.

TfL has had some trials on hydrogen buses, but this has been at significant cost with limited positive results. TfL remains buoyant about the future of hydrogen vehicles, but their main focus is now on increasing use of hybrid technology, with planned trials from several manufacturers over the short term followed by significant roll-out to the fleet.

There are limited trials of biofuel options currently, with a couple of high blend options from waste and ethanol. These are limited by supply at current technology, resulting in the main thrust being low blend supplied at pump for biodiesel.

Effort and research is being made by TfL to understand the real CO_2 benefits of biofuel.

5.2 Europe

Trials of ethanol fuelled buses are significant in Europe, but there is also a strong effort in terms of trolley bus applications – either purely grid based, or with hybridisation using battery or ICE generators. Some of these applications are historic (Eastern Block or China where the infrastructure still exists), and there is also an emergence of new schemes where the lower infrastructure costs compared with Light Rail and trams makes it economic for lower density passenger numbers, yet it still attracts similar patronage as trams.

5.3 USA

Significant effort has gone into CNG schemes for tailpipe emission benefits compared against diesels with high sulphur fuel and no after treatment. This effort has resulted in the establishment of considerable infrastructure, so there is an inertia that exists in the marketplace for CNG buses. Recently comparisons have been made with hybrid technology and cities such as Houston and New York have chosen hybrid technology as their preferred solution for a combination of reducing tailpipe emissions and GHGs.

The car market has always been dominated by gasoline, which results in significant effort going into research into ethanol from Generation 2 biofuel production. If high volume processes are developed, then this would significantly influence the fuel for buses with a potential shift to ethanol as with European trials.

6 Alternative Fuels in the SEStran Area

A significant proportion of the projects shown in the appendices are funded by state support to technology under the primary aim to reduce either energy consumption or GHGs. The majority of projects with alternative fuels or technology would not self fund at this stage due to:

- Development costs
- Reliability
- Vehicle costs
- Infrastructure changes – either fuel or servicing

The current UK grant system to support buses does not favour or support a goal of reducing GHGs. Alternative fuels are not currently competitive, hence the only way forward is to find grant funding.

6.1 Grants System used to Develop Bus Fleets in all Cases

In order to obtain a grant for trial vehicles, it is necessary to

- Demonstrate how the scheme would fit within the goals for the funding
- Assemble a consortium to take forward the trial vehicles
- Apply for the grant with the business model showing the benefits in terms of GHGs, energy security, modal shift etc

Potential support funding could come from bodies such as EST, European Framework Programme (FP).

An alternative way forward is to combine a demand management scheme (e.g. congestion charging) with a scheme that will increase bus modal shift (e.g. trolley bus) and apply for loans that will be repaid by the demand management scheme. This is being considered in Greater Manchester, Cambridge and East Midlands under TIF funding.

7 Analysis and Summary

7.1 Tailpipe Emissions

The market for alternative fuelled vehicles expanded in earnest in the late 90s with comparisons made between Euro I (Oct 1993) and Euro II (Oct 1996) emission regulations. These regulations, although a step change at the time, still allowed significant levels of pollution from the diesel fleet and in particular NOx and PM. At that time, alternative fuels offered significant local emission benefits compared with existing diesel technology.

The major driver at the time was local tailpipe emissions rather than greenhouse gases and fuel economy, which further highlighted the advantages offered by the alternative fuel market and in particular CNG. This significant improvement offered enough incentive to consider the infrastructure costs and supply issues for fuels that were not readily available, and for vehicle technology which was immature.

The alternative fuel streams were mostly fossil fuel based and so provided little benefits in resource depletion, energy security or greenhouse gas reduction.

Since then, we have seen significant improvement in diesel emissions brought about by the change to ultra low sulphur diesel. We are also now at Euro IV levels of emissions, and these are significantly closer to the tailpipe values achievable through alternative fuel use.

With the availability of powertrain technology such as EGR, particulate traps, and SCR, there are opportunities for both retrofit and OEM supplied option at new purchase. These technologies can reduce emissions even further beyond the current regulated values.

With the current situation, it is unlikely that an alternatively fuelled vehicle, running on CNG, LNG or LPG would offer an advantage in reducing local tailpipe emissions.

7.2 Greenhouse Gas Emissions

Looking forward, we must consider the likelihood of binding legislation developed around GHGs and focusing on more than the Tank to Wheel phase which is currently measured by fuel economy. The tailpipe emissions will fall away in importance as fleets are replaced and more vehicles are at Euro V and possibly Euro VI based around EEV levels. The focus will then be on GHGs. Fossil fuel based alternative fuels will not provide any real benefit over diesel, so we will need to look at renewable alternative fuels; electricity (derived from a high mix of renewables), and improvements in energy efficiency (through hybridisation of city vehicles). Some niche fuels may be viable, but these need to be agreed and developed locally as a solution with producers, transport authorities and infrastructure providers working on a holistic approach (e.g. biomethane derived CNG from waste).

Within this report the uncertainties are highlighted, and principal of these is the knowledge of when we will have production feasible Generation 2 biofuel derived from feedstocks that have a high yield per hectare of land. Ethanol and biodiesel are the current favourite biofuels, with a predicted carbon abatement cost that is lower than the others.

7.3 Energy Security

The second driver in the medium term will be energy security. Focussing on alternatives to diesel will help with energy security, but a choice of electricity through the use of off-grid capable trolley-buses will offer all fuel options in the mix, as well as an easy route to renewables such as wind, wave and PV cells.

8 Recommended Roadmap to Reduced Emissions

Short, medium and long term strategies are recommended. The short term strategy aims to minimise tailpipe emissions in the inner city. The medium and long term options reflect our belief that tailpipe emissions will reduce in importance, and GHG reduction and energy security for transport will become significant.

The key finding is to consider moving the fleet towards electrification as an alternative fuel. This is initially focused on series hybrid buses, with a staged uptake of biodiesel or ethanol, followed by an infrastructure and scheduling review to establish a city trolley bus network with off-grid capability linked to the proposed tram network but focusing on reduced patronage corridors.

For out-of-city use, a network of biofuel buses would be most suitable but further detailed bus route analysis will be required to understand the optimum solution to achieve lower GHG emissions.

This can be summarised as:

- Inner city high density high stop-start: solution is trolley buses using electricity
- Intercity typified by higher speed and reduced stop-start: solution of high mix biofuel - probably biodiesel or ethanol but only from Generation 2 fuel sources
- Mixed use vehicles running hybrid technology and biofuel as before

This policy offers

- Zero emissions at point of use in the inner city with low carbon fuel used outside the city where low traffic density renders tailpipe emissions less important.
- Energy security in terms of feedstock fuel: - electricity can be generated from a variety of primary sources.
- Efficiencies in transport energy consumption across the fleet by means of hybridisation and regenerative braking – resulting in improved overall fuel efficiency primarily in the inner city.
- Overall shift of carbon emissions from transport to the generating sector where it can be more effectively dealt with at a reasonable price through the wider adoption of combined heat power plants.
- Optimal use of waste heat within the generating sector.

8.1 Breakdown of Recommended Strategy

Translating the above into a more detailed strategy will require consideration of the existing fleet in the short term and planning of activities and infrastructure for the long term solution. The biofuel debate needs a watching brief as it develops over the next 5 years.

8.1.1 Short Term

- Undertake a detailed study of the adaptability of the existing vehicle fleet to diesel after treatment. Upgrade existing fleet of vehicles with retrofit emission reduction devices – particulate filters and EGR where appropriate.
- Develop a plan to optimise the existing fleet carbon footprint with respect to the city centre.
- Develop an accelerated programme to replace older vehicles with Euro IV vehicles with added technology for 'Enhanced Environmentally friendly Vehicles' (EEV). This will lead to a higher purchase price for particulate filtering and potentially catalytic reduction options, but the vehicles will then be Euro V, and possibly EEV compliant.
- Perform a trial of a series hybrid bus fleet on key routes and investigate with suppliers the potential for a zero emission and plug-in capability, to provide a zero tailpipe option through local pollution hot spots. Note that whilst this reduces emissions overall, there will be some emissions transferred to another area.
- Investigate the availability of biodiesel and ethanol and determine the more suitable alternative fuel for minimised fleet servicing and infrastructure changes.

8.1.2 Medium Term

Invest in an understanding of how a city network of modern trolley buses can be incorporated into a fleet of series hybrid buses (with plug in capability to allow off-line operation). This should include scheduling and transport planning activities together with a full financial model and the development of a carbon reduction plan (Business as Usual compared with the reductions achievable through electrification).

Monitor the progress of other authorities developing low carbon fuels, with a view to adopting successful technologies when matured.

Undertake a study to investigate the available waste within the region and balance this with bus fleet demand to see what is feasible for niche use of biomethane.

8.1.3 Long Term

Work with European Framework Programmes to investigate crossover technology between trolley and hybrid buses to enable a significant trial of vehicles that can switch between grid and off grid battery hybrid electric operation.

The hybrid vehicles will probably work with either hi blend biodiesel or ethanol.

Monitor research on the use of hydrogen rather than B100 (100% biodiesel) as a fuel for the hybrid. However city zones may have already been converted to electrification through grid and off grid technology and do not require hydrogen for zero emissions. Also, outside the city centre, the benefit of zero emissions may not outweigh the additional cost and poor Well To Wheel performance of hydrogen.

8.2 Recommended Next Steps

The data contained in this report is based on general performance figures for fuels and technologies. A detailed study of energy usage, energy efficiency, carbon efficiency, and local emissions hotspots is now required to identify the optimum future plan.

We recommend the following process to move forward.

- Establish typical drive cycles for buses within the region and understand the proportion of time inner city v extra urban.
- Generate a "Business as Usual" case for energy and CO_2 consumption, in conjunction with vehicle movements in hot spot areas of the city which have local emission concerns.
- Using computer modelling with the generated drive cycle data, define a specification for a series hybrid bus, using biodiesel. This will enable the hot spots to be traversed on battery alone,
- With the specification for a series hybrid bus and plug-in capability, model and evaluate the level of local pollutant reduction, together with the reduction in energy usage and greenhouse gases for the fleet.
- Work with vehicle manufacturers to develop the specification and supply of a trial fleet of vehicles.
- Work with grant bodies to establish a financial framework to enable the evaluation of a fleet of 'zero emission capable series hybrid buses'. These will demonstrate the potential to reduce local emissions and greenhouse gases for a typical large city. Note that the work undertaken in London does not require zero emission zones or plug-in capability, and London has a very specific drive cycle which is not applicable to Edinburgh.

A medium term project to run in parallel with the above would be to evaluate the trolley bus opportunity for Edinburgh as follows:

- Map the existing fleet movements, and understand the most suitable network of trolley bus infrastructure within the restrictions of the tram network and a multi-operator system.
- Generate a new trolley bus network and identify the new schedule to understand best fits, including corridors or ring routes operated by a single company. This schedule should link trams, trolley buses, mixed use hybrids and inter city vehicles holistically to ensure a joined up network to increase PSV patronage.
- Generate a specification for trolley buses that fits with this schedule, and revisit the series hybrid bus fleet to understand how it fits within the new schedule.

- Identify energy saving based on the new electrification network and the energy volume transferred from transport to generating sector.
- Discuss the effect and opportunities of the increased electrical energy load with local electricity suppliers.
- Identify additional reduction of local emissions. This will include assumptions on modal shift, based on increased vehicle utilisation when using trolley buses compared with conventional diesel buses.

A1 Stagecoach Biofuel

Authority or Region - East Ayrshire Council

Trial dates

Trial commenced 26.10.06
Conclusion 26.4.08

Participants

- Stagecoach
- Argent Energy

Vehicle

Alexander Dennis buses with MAN dual-fuel engines.

Objective

Six month carbon reduction programme, evaluating. 8 vehicles in the Kilmarnock area running on 100% biodiesel manufactured from cooking oil and other food industry by products. Green incentive scheme providing passengers with discounted bus travel in exchange for recycled cooking oil. All households on the Service 1 route have received a container to recycle their used cooking oil. These can then be exchanged for vouchers towards bus travel. Projected to reduce CO_2 by 82% and produce an annual saving of 960 tonnes of carbon

Outcome

The trial is currently in progress, so no results are yet available

Next Steps

tba

Reference

Stagecoach press release 26.10.07 Need data of the benefits to the community if possible i.e. the inclusion of people into solving the problem, the cost saving to them if any etc – This is a good one as it fits to our conclusions, and also is stagecoach

www.stagecoach.com

A2 Scania Ethanol

Authority or Region - Reading Transport

Trial dates

Commenced 23.11.07
Ongoing

Participants

- Scania GB Ltd
- Reading Transport Ltd
- British Sugar Ltd

Vehicle

Scania OmniCity double decker – 14 off

Objective

An evaluation of the use of E95 ethanol, produced at British Sugar's plant in Wissington in Norfolk

Outcome

Results not yet available

Next Steps

tba

Reference

Scania press release
www.scania.co.uk
NB Nottingham City Council will take delivery of 3 Scania OmniCity ethanol powered buses during December 2007.

A3 CATCH – Task 1

Authority or Region - Liverpool City Council

Trial Dates

Particulate filters	2003
Particulate filters and EGR	2004

Participants

- Liverpool City Council

Vehicle

88 vehicles were fitted with particulate filters in 2003, and in 2004 a further 16 vehicles were fitted with combined EGR and particulate traps. This represented 10% of the fleet in Merseyside.

Objective

To reduce particulates by 95%, CO and HC emissions by 90%, and NOx by 15%

Outcome

There were a number of problems with the particulate filters caused by poor manufacture and installation. From the evaluation report average particulate reductions were 98% and NOx was reduced by 35%. No values are given for CO and HC.

Fuel consumption was 4.3% worse, which was believed to be influenced by the problems with the particulate filters.

Next Steps

N/A

Reference

www.merseytravel.gov.uk

A4 CNG Fuelled Busses in North West of England

Authority or region

Arriva North West and Wales

Trial dates

Trial commenced	February 1999
Trial concluded	September 1999

Participants

- Arriva North West and Wales
- Merseytravel SMARTeco
- Passenger Transport Executive
- EU funding via Jupiter-2
- Mobil Oil (refuelling station)

Vehicle

4 buses were used, make unknown, running on CNG

Objective

The purpose of the trial was to encourage a modal shift from the use of cars in the centre of Southport. To reduce exhaust pollution, save energy and demonstrate sustainable transport in the region. The trial was over a 9 month period in 1999.

Outcome

- The perceived environmental impact of the CNG buses was about half that of cars and diesel buses. The operating performance of the vehicles was worse than clean diesel and electric buses (what was the electric busses project>?) which were also operating in the area. The vehicles exhibited worse reliability than conventional diesel buses.
- Fuel costs are dependent on the duty applicable at any particular time, but a study at the time of the trial net fuel costs were 9p/km for CNG compared with 7p/km for a conventional diesel.
- After 9 months of operation the CNG services showed a 5% increase in usage compared with the 2 preceding years.

Next Steps

Without government funding, there is no commercial incentive to use CNG, and with on-going improvements in diesel emission management, no further testing is planned.

Reference

www.idea.gov.uk

A5 TfL Particulate Filters

Authority or Region
TfL
Trial dates
Commenced 1999
Ongoing
Participants
TfL
Millbrook Proving Ground
Vehicle
All 8000 buses in the TfL fleet have now been fitted with diesel particulate filters
Objective
To reduce particulate, carbon monoxide and hydrocarbon emissions
Outcome
90% reduction of particulate, CO and hydrocarbons as measured in the Millbrook London Transport Test Cycle
Next Steps
Ongoing
Reference
www.tfl.gov.uk

A6 TfL Hydrogen Fuelled Buses

Authority or region - TfL

Trial dates
Scheduled to commence in 2010
Participants
SI engined buses
- ISE
- Wrightbus
- First Group

Hydrogen fuel cell buses
- Mercedes Benz
- Ballard

Vehicle
TfL plans to have 10 hydrogen powered vehicles in operation in London by 2010.
5 vehicles fitted with SI V10 engines running on hydrogen (probably US Ford engines)
5 vehicles fitted with hydrogen fuel cells
Objective
To make real world assessment and comparison of the 2 systems.
Reduced tailpipe emissions
Outcome
The buses are planned to be operational by 2010
Next Steps
N/A
Reference
www.tfl.gov.uk

A7 CATCH – Task 2

Authority or Region - Liverpool City Council

Trial Dates

Commenced	March 2005
Conclusion	June 2005

Participants

- Liverpool City Council
- Optare
- Eneco

Vehicle

Optare Solo converted to a diesel hybrid by Eneco . VW TDi engine

Objective

To assess the use of hybrid buses in Liverpool city centre. A new circular route was established for the trial at Princes Dock in Liverpool. The buses were operated over a period of 18 weeks, starting in March 2005, with a frequency of 15 minutes.
Length of route unknown.
IC engined buses were used as back-up when the hybrids were not available.

Outcome

The vehicles achieved 58% of the potential mileage over the 18 weeks. It was recognised that these were not production vehicles and a degree of unreliability was expected, which would normally be "developed out" on a production vehicle. Problems ranged from minor hose failures to 2 engine failures on one bus (rectified by VW under warranty).

Reference

www.cleanaccesibletransport.com

A8 FTR

Authority or Region - City of York Council

Trial dates

Commenced	2.6.06
Concluded	Ongoing

Participants

City of York Council
First Group

Vehicle

Wrightbus

Objective

Pilot scheme to introduce the ftr project in York. The ftr is the Wrightbus StreetCar, which is a hybrid articulated vehicle, 18,7m long, with a capacity of 114 passengers.
Leeds City Council and Metro, in conjunction with the First Group, launched a fleet of 17 ftr vehicles operating over a 21.5km route. The vehicles cost a total of £5.4m.

Outcome

Feedback from York after 12 months of service showed high levels of customer service.

Next Steps

The ftr will be launched in Swansea in early 2009.

Reference

www.goftr.com/leeds/news

A9 Alexander Dennis Hybrid Bus

Authority or Region

Trial dates

Participants

Alexander Dennis
Energy Saving Trust
Newbus Technology Ltd

Vehicle

Alexander Dennis Enviro 200H single decker
Cummins ISBe engine
320V Varta NiMH batteries – roof mounted
Regenerative braking

Objective

The project was funded by the Department for Transport, managed by the Energy Saving Trust.
The purpose was to understand the issues in building and operating a hybrid bus. The vehicle was designed to minimise the differences between this and a conventional bus.

Outcome

The vehicle undertook the Low Carbon Bus test at Millbrook in 2005, achieving a 37% reduction in CO_2 . Alexander Dennis believes that this can be improved to 40%.

Next Steps

The bus was loaned out for evaluation in 2006.

Reference

http://www.energysavingtrust.org.uk

A10 Lincoln Electric Buses

Authority or Region - City of Lincoln

Trial dates

Commenced	16.6.04
Concluded	16.6.05

Participants

City of Lincoln
Energy Saving Trust
Leyland Product Development
Renault

Vehicle

Renault Master 14 seat mini bus
Battery only

Objective

To assess the viability of running battery buses in a city environment, and thus to improve air quality in the city.

Outcome

The vehicle operated between the shopping area and the Cathedral, making 3 trips per hour.
The vehicle was well received by passengers
The maximum range of the vehicle was found to be 75.3km
Zero tailpipe emissions
Energy consumption 671 Whr/km
Well-to-Wheel equivalent CO2 emissions was 289gms/km (based on electricity generation)
The project was funded by:

- Lincoln City Council
- PowerGen
- The Energy Saving Trust

Next Steps

N/A

Reference

http://www.energysavingtrust.org.uk//fleet

A11 Oxford Electric Buses

Authority or Region - Oxford City Council Stagecoach

Trial dates

Commenced	1994
Concluded	1998

Participants

Stagecoach
Southern Electric

Vehicle

Optare 18 seat bus
Battery only

Objective

To assess the viability of running battery buses in a city environment, operating between the station and the university science area.

Outcome

The vehicles were designed to operate on a fixed route between the station and the university science area. Opportunity charging was provided at the station terminus, which enabled the vehicles' duty cycle to be greatly extended.

There were a number of teething problems with the vehicles' batteries and recharging regimes. Once these were resolved the vehicles operated successfully for 4 years with one change of batteries (as a result of damage). They were taken out of service in 1998 when the county council withdrew its subsidy for the annual running costs of £100,000.

Next Steps

N/A

Reference

http:archive.oxfordmail.net/1998/2/18/86789.html

Appendix B

European Projects

B1 Stockholm

Authority or region
Storstockholms Lokaltrafik

Trial dates
Ethanol powered buses have been in service since 1989

Participants
- Scania
- Storstockholms Lokaltrafik
- Swedish Energy Agency

Vehicle
City buses

Objective
All public transport in Stockholm has to use renewable fuel. Since 1989 Scania has manufactured over 600 city buses running on E100 ethanol for use in various Swedish cities. Some 400 of these are in Stockholm.

Outcome
These vehicles are operated as normal fleet vehicles.

Next Steps
During 2008, Scania and SL, with funding support from the SEA are going to carry out tests of series hybrid buses. Power is from an ethanol fuelled diesel engine driving a generator, with regenerative braking. Electricity is stored in supercapacitors, which are claimed to have a longer service life than batteries.

The Swedish Energy Agency is providing SEK 16m (£1.2m) of funding for the project.

Reference
Scania press release 21.2.07 www.scania.com

B2 Project Biogas, Bern, Switzerland

Trial dates
Commenced 2006

Ongoing

Participants
- Bernmobil
- Volvo Bus

Vehicle
32 Articulated buses fitted with Volvo 7700 9 litre biogas engines.

This engine is Euro 5 and EEV compliant

Since 1992 Volvo has produced over 1000 gas powered vehicles.

Objective
Bernmobil is replacing its diesel buses with gas ones to reduce pollution in the city. 32 gas powered were ordered for delivery in 2006, with an option for a further 39.

Outcome
No further information available

Next Steps
N/A

Reference
Volvo press release: www.volvo.com/bus

B3 Biogas Hybrid, Uppsalabuss AB, Sweden

Trial dates

Commenced 1998
Conclude 2000

Participants

- AB Uppsalabuss
- Gottlob Auwarter GmbH
- Skanetrafiken
- Funded by the Thermie programme

Vehicle

4 Neoplan Metroliner MIC 8012 GE modified as follows:

- Wheel motors on each rear wheel
- Bio gas powered engine driving a generator
- NiMH batteries
- Regen braking

Objective

Reduction of CO_2 emmisions by 30%
Zero emission operation in limited restriction areas.

Outcome

For a variety of systems faults initial availability was below 20%, but this increased to over 50% during the later stages of the project. The problems were a combination of new technology and a lack of development. The engines were not optimised for operation in a hybrid and so emissions were higher than expected, and similar to a diesel engine.

In hybrid operation emission levels measurements showed that:

- CO_2 emissions can be reduced by 30%
- CO emissions can be reduced by 60%
- NOx emissions can be reduced by 50%

Next Steps

N/A

Reference

www.uppsalabuss.se

B4 Electric Buses, Castello, Spain

Trial dates

Commenced December 2007
Ongoing

Participants

- Castello City Council
- Civis

Vehicle

An electric guided bus, with batteries driving through wheel motors, and a passenger capacity of 41. It runs between the city centre and the outskirts, and can operate for four hours before recharging.

Outcome

No further information available

Next Steps

N/A

Reference

www.autobloggreen.com

B5 Trolley (Electric) Buses

Trolley buses are currently in use in 326 cities in 49 countries throughout the world. They are predominantly in less developed economies such as the old soviet bloc and China, with a number in Central and Western Europe.
The major limitation of any trolleybus system is their inability to operate away from the overhead wires, making any re-routing a costly and time consuming exercise. To provide greater flexibility, a number of operators have added range extenders to their vehicles.
In San Francisco and Vancouver the trolley buses are fitted with battery packs to allow limited (up to 10kms) operation “off line”. Rome’s trolley buses also have batteries, which enables them to operate in the old parts of the city where overhead lines are not permitted. Boston is using dual mode trolleybuses equipped with diesel engines allowing them to operate off-line, and in Athens, which has a fleet of 366 trolleybuses, all new vehicles since 2004 have been fitted with diesel engines.

European Manufacturers

Neoplan	- Germany
Mercedes	- Germany
MAN	- Germany
Hess	- Switzerland
Volvo	- Sweden
Iveco/ Irisbus	- Italy
Van Hool	-Holland
Skoda	Czech Republic
Solaris	Poland

European Users

Austria	2 cities
Belgium	1 city
Czech Republic	13 cities
France	4 cities
Germany	3 cities
Greece	1 city
Holland	1 city
Hungary	3 cities
Italy	17 cities
Norway	1 city
Poland	3 cities
Portugal	1 city
Sweden	1 city
Switzerland	14 cities

Source:-http://members.aol.com/trolleybusscene/index.htm

Cities where alternative power is being used for buses include:

Arnhem – hybrid Van Hool bus
Bologna – 233 electric/methane hybrids
Athens – 295 gas powered buses, 366 hybrid trolley buses
Vancouver – 228 new hydro-electric trolley buses operating over 300kms of routes in the city

Appendix C

North American Projects

NGVAmerica reports that there are 10,000 natural gas powered buses in North America, operated by125 transit authorities. This represents 12% of the transit bus fleet. 20 – 25% of all buses now on order will be natural gas powered.

Reference www.greencar.com/features/alternative-transit

This reflects the USA's historic preference for gasoline and hence spark-ignition engines. Gasoline has always been cheap and plentiful, and as a result, until recently, there has not been pressure or incentive to use diesel engines.

C1 Project 2010 Winter Olympics

Trial dates
2010

Participants
- New Flyer Industries]
- BC Transit Bus

Vehicle
40 ft low floor bus. BC Transit has ordered 20 vehicles, which will be powered by Ballard fuel cells, with an ISE drive system

Objective
The vehicles will be used for the 2010 Olympics, and will be based in Whistler, British Columbia.

Outcome
No further information available

Next Steps
N/A

Reference
www.greencar.com/features/alternative-transit/

C2 Van Hool hybrid electric in California

Participants

- SunLine Transit (California) (1vehicle)
- AC Transit (California) (3 vehicles)
- ISE Corp

Vehicle

Van Hool A330 transit bus

- ISE Thundervolt TB-40FCH fuel cell hybrid-electric drive system
- 120Kw fuel cell supplied by UTC Power
- Hydrogen fuel at 5000psi

- Zebra 650volt nickel sodium chloride batteries
- Siemens 85kW traction motors x 2
- Siemens ELFA drive system

Reference

www.greencar.com/features/alternative-transit/

C3 Los Angeles

Dates

Commenced 2006

Participants

Los Angeles Metro

LA Metro has a fleet of 2500 buses, of which 2200 were CNG powered by the end of 2006. All vehicles will be CNG powered by 2008/9

Orange County in California has 299 New Flyer CNG powered buses

Reference

www.busandcoach.com

C4 San Francisco

Trial dates

Commenced June 2006

Ongoing

Participants

- San Francisco Muni
- Orion (Daimler Benz)

Vehicle

56 Orion VII diesel-electric hybrids fitted with BAE Systems' HybriDrive

Objective

Improved fuel consumption and reduced emissions

Outcome

HybriDrive has been shown to reduce fuel consumption by 30% and emissions by:

PM	30%
NOx	40%
GHG	30%

Next Steps

N/A

Reference

www.busandcoach.com/

NB The Toronto Transit Commission also has 150 of these vehicles

C5 New York

Trial dates

Commenced Approx 2000

Ongoing

Participants

- Metropolitan Transportation Authority
- New York State Energy Research and Development Authority

Vehicle

Diesel hybrid transit bus

Objective

Reduced emissions

Outcome

The MTA successfully trialled 10 diesel hybrids in the city, following which a total of 825 buses were ordered for New York City.

The diesel engine has a particulate filter and uses ULS fuel

Fuel consumption is reported to be 25 – 35% less than for a standard bus

Emission reductions:

PM	90%
NOx	40%
GHG	30%

Next Steps

N/A

Reference

www.busandcoach.com/