transport**energy**

# The Route to Cleaner Buses

## A guide to operating cleaner, low carbon buses


Energy Saving Trust

Department for Transport

catch

# Preface

Over recent years, concerns have grown over the contribution of emissions from road vehicles to local air quality problems and to increasing greenhouse gas emissions that contribute to climate change. One result of this is a wider interest in cleaner vehicle fuels and technologies. The Cleaner Bus Working Group was formed by the Clear Zones initiative and the Energy Saving Trust TransportEnergy programme. Its overall aim is to help stimulate the market for clean bus technologies and products. Comprising representatives of the private and public sectors, it has brought together users and suppliers in an effort to gain a better understanding of the needs and requirements of each party and to identify, and help overcome, the legal and procurement barriers.

This guide is one output from the Cleaner Bus Working Group. It investigates the potential benefits and the issues associated with the use of 'cleaner' vehicle fuels for bus operation in urban areas. The prime aim of the guide is to help local authorities to gain a better understanding of the technical and economic issues involved in cleaner fuel buses, and to take forward appropriate actions to promote their use.

A Clear Zone is a defined urban area, which exploits new technologies and operational approaches to improve quality of life and support economic growth, whilst minimising the adverse impacts of its transport systems. The Clear Zones initiative seeks to develop this concept and promote the development of relevant technology through partnerships between cities, industry, academia and government. Clear Zones is co-ordinated by Transport & Travel Research Ltd, and supported by the Department for Transport.

TransportEnergy is funded by the Department for Transport and the Scottish executive to reduce the impact of road transport through the following sustainable transport programmes: PowerShift, CleanUp, BestPractice and the New Vehicle Technology Fund. These programmes provide advice, information and grant funding to help organisations in both the public and private sector switch to cleaner, more efficient fleets.

CATCH is a collaborative demonstration project co-financed by the European Commission's LIFE-ENVIRONMENT Programme. CATCH is co-ordinated by Merseytravel, with Liverpool City Council, Transport & Travel Research Ltd, ARRIVA North West & Wales Ltd, Compagnia Trasporti Pubblici (Naples) and Suceava Municipality (Romania) as partners.

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Life

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# Executive Summary

UK road transport contributes to national emissions of gaseous pollutants, which can lead to both global climate change and a variety of local air quality problems. The UK bus fleet is predominantly powered with diesel using compression ignition engines. Alternative 'clean' transport fuels, which offer the prospect of reducing some of these emissions and improving energy efficiency, are currently available, and include:

- Liquefied petroleum gases and compressed natural gas used in internal combustion engines;
- Hybrid electric vehicles which combine electric motor drives with internal combustion engines fuelled by diesel or petrol;
- 'Biodiesel' fuel used in internal combustion engines in blends with diesel fuel.

There are also longer-term prospects of using other 'low carbon' fuels such as bioethanol, biomethanol and hydrogen fuel cell technology.

The costs and benefits of using clean fuels in public transport vehicles need to be compared with the use of ultra-low sulphur diesel fuel in vehicles complying with current EU emissions standards (Euro III). All forms of alternative road fuels have advantages and disadvantages – for example: capital and operating costs, emissions, refuelling infrastructure and refuelling time, vehicle range, and loss of payload space. Hence changing from diesel fuel requires careful consideration. Apart from cost factors, the levels of emissions make some fuels more suitable for certain types of uses than others. The potential introduction of Low Emission Zones in some city centres, and the provision of congestion charges which could offer exemptions for low emission vehicles are major commercial factors that must be considered for urban bus operation. Clean fuel buses may be a solution. The tax, duty and grant regime in place can have a major impact on fuel choice.

The key factors involved in each of the clean fuel alternatives that are currently available are listed in the following Table.

Operating experience from several case studies in the UK and elsewhere have demonstrated some of the environmental benefits of reduced emissions of local air pollutants and greenhouse gases from the use of alternative cleaner fuelled vehicles. However the total lifecycle costs of these vehicles, taking into account the operating costs, capital expenditure and maintenance costs, are greater than those for the equivalent buses operating on ultra-low sulphur diesel fuel. Hence the economic case for cleaner fuels is not commercially attractive to bus operators. Although several of these alternative fuels have lower rates of fuel duty than are applied to ULSD, the current Fuel Duty Rebate system (Bus Service Operators Grant) for bus operators reduces the incentive to switch to alternative fuels. Before large-scale market uptake becomes likely, the cost of alternative fuel powered bus operation needs to become comparable with diesel.

Government grants are available towards the additional cost of purchase or conversion to a cleaner fuelled vehicle, funded by TransportEnergy through the PowerShift programme. The New Vehicle Technology Fund and CleanUp Demonstration programme also part-fund demonstration and research projects into clean bus systems, and programmes funded by the European Union may also be relevant.

Hydrogen fuel cells are often promoted as the fuel of the future given that it offers the possibility of zero emissions. Most major manufacturers have extensive R&D projects underway, with evaluation trials on buses, cars and vans already in progress. However, commercially viable versions of this technology are approximately 15-20 years off. Apart from getting the technology to work reliably in everyday working environments, there is also the question of how the necessary re-fuelling infrastructure is to be put in place, and the investment costs that would be required.

The eventual market for alternative fuels and technologies in bus operation will be strongly influenced by:

- The predicted costs and benefits to the customer and operator being commercially acceptable;
- Fuel tax and subsidy arrangements applicable to the UK bus industry;
- Whether there are access restrictions to some urban centres for all but low-emission vehicles;
- How much increasingly stringent European emissions control legislation may favour alternative fuels;
- The extent of other benefits from alternative clean fuels such as performance improvements, quiet operation and improved fuel economy.

| Fuel Type | Pros | Cons |
|---|---|---|
| **Water Emulsion Diesel** | Lower emissions of NOx and particulate matter, possible $CO_2$ benefits from improved fuel consumption. No modifications needed to engine. | Only one supplier in the UK. |
| **Liquefied Petroleum Gas (LPG)** | Low $CO_2$ emissions, similar to diesel; generally low levels of other pollutants; low levels of engine noise; low fuel duty compared with diesel. | Currently limited but expanding refuelling infrastructure (1200 sites in UK); lower fuel economy; often loss of some load space; issues regarding toxicity and the combination of high density and flammability of the gas. |
| **Compressed Natural Gas (CNG)** | Low $CO_2$ emissions, similar to diesel; generally low levels of other pollutants; low levels of engine noise; low fuel duty compared with diesel. Vehicles widely available in Europe. | Currently limited refuelling infrastructure therefore requires dedicated refuelling equipment; lower fuel economy; loss of some load space (more so than LPG); vehicles are currently significantly more expensive to purchase and maintain than diesel buses; experience of unreliability in early trials |
| **Battery Electric Vehicles** | Zero emissions at point of use; extremely cheap fuel; silent operation | Requires recharging systems; batteries and vehicles can be expensive; pollution created at power station not exhaust pipe; limited range between charges; battery durability |
| **Hybrids (Electric/Diesel)** | Low $CO_2$ and other pollutants; very fuel efficient; driving experience very similar to diesel vehicle; only fuel required is diesel therefore plentiful - no need to recharge batteries separately although some require charge stabilisation, once or twice per week | New technology, so at present vehicles are expensive; also currently limited vehicle choice. The widespread introduction of hybrids would require new skills for maintenance staff and electrical technicians. |
| **Biodiesel (blended with ULSD)** | Lower $CO_2$ emissions on a 'life-cycle' basis plus a reduction in particulate matter and hydrocarbons; driving experience very similar to diesel vehicle; no modifications needed to the engine; lower fuel duty for the biodiesel component compared with diesel. | Development of refuelling infrastructure still in early stages; a blend of only up to 5% biodiesel is acceptable to some engine manufacturers under existing warranties. Slight increase in NOx emissions compared to standard ULSD. |

# Introduction

New technologies that are available now, together with those that are starting to come on stream, can offer the chance of a different future for road transport – one that involves quieter and less polluted city centres with vehicles operating on clean and sustainable fuels. Buses have a key role to play in this vision, since they are high-profile vehicles, many of them operating in congested urban areas where their environmental performance is important. Furthermore, buses are depot based, and can be useful in demonstrating and promoting new vehicle fuels and technologies. They provide an important early market for the road vehicle technologies of the future.

Three key environmental concerns form the background to introducing clean fuel buses:

## Air quality

Road transport is one of the main sources of air pollution in the UK. The main air pollutants from road vehicles include carbon monoxide, unburnt hydrocarbons, oxides of nitrogen and particulate matter. Whilst there have been considerable strides in recent years in reducing emissions of these and other pollutants, through technical changes in vehicles and improvements in fuels, there remains much to be done. The Government published its
Air Quality Strategy in 2000 and 1st Addendum in 2003. These have set standards for the key pollutants and objective dates for their achievement across the UK. Reducing air pollution from road transport will play an important role in helping to meet these objectives.

Local authorities have statutory duties for local air quality management (LAQM) under the Environment Act 1995, which extended their powers under the Road Traffic Regulations Act 1984. They are required to carry out regular reviews and assessments of air quality in their area against standards and objectives in the national Air Quality Strategy and which have been prescribed in regulations for the purpose of LAQM. Where it is found these are unlikely to be met, authorities must designate air quality management areas (AQMAs) and prepare and implement remedial action plans in order to tackle the problem. These action plans must indicate the measures that they and others will undertake that will work towards achieving the national air quality objectives. Some local authorities are planning to introduce Low Emission Zones, namely defined areas from which polluting vehicles that do not comply with set emissions standards are barred from entering.

## Climate Change

The UK has legally binding targets to reduce greenhouse gas emissions by 12.5% below 1990 levels over the period 2008-2012. In addition, the Government set a domestic goal of cutting the UK's emissions of carbon dioxide by 20% below 1990 levels by 2010. Road transport is the third largest source of greenhouse gas emissions, and is currently responsible for 22% of all UK emissions. Transport is also predicted to be the fastest growing source of greenhouse gas emissions. Tackling the carbon dioxide emissions from road transport will be a key factor in helping the UK to meet its climate change commitments. The Government's Powering Future Vehicles Strategy has also set out a target that by 2012, 600 or more buses coming into operation per year will be low carbon, defined as 30% below current average carbon emissions.

## Noise pollution

Road traffic noise can be the cause of significant community annoyance and as such be detrimental to people's quality of life. A commitment to sustainable development requires action to be taken to improve this. The Government is committed to developing a more stringent approach to addressing the problems caused by environmental noise and in 2008 Directive 2002/49/EC, relating to the assessment and management of environmental noise, will require the development of action plans to manage the road noise climate. Reducing noise emissions from vehicle engines can make an important contribution to this process.

## A role for cleaner buses

Cleaner buses can help mitigate these environmental concerns. The potential environmental benefits of the wider use of cost-effective clean vehicle fuels and technologies in bus operation are:

- Reduced emissions of the regulated air pollutants. For buses operating in urban areas, improvements in the local air quality can be obtained, so helping to achieve the air quality management objectives of the local authority;
- Some alternative fuels can provide lower levels of greenhouse gas emissions, when assessed on the basis of the fuel's complete life-cycle (ie. the 'well to wheels' assessment of the complete fuel production, supply and end-use);

- Lower levels of vehicle noise, since engines using alternative fuels are often less noisy than those using conventional fuels.

Despite these potential benefits there are several barriers to the uptake of clean buses, including:

- The availability and suitability of clean bus technologies and fuels, including difficulties in sourcing and specifying;
- The unwillingness of operators to use them due to problems that have been experienced during early deployment of some technologies;
- The possibility of negative responses of the general public due to unfamiliarity and low levels of awareness;
- The extent to which air quality and other environmental benefits are obtained;
- The increased capital and operating costs;
- The performance and maintenance implications.

The Government published its strategy entitled 'Powering Future Vehicles' in July 2002, with the main objective 'to promote the development, introduction and take-up of new vehicle technologies'. In terms of clean fuel buses, the strategy sets a target for 600 or more of new bus registrations to be low carbon (expected to be at 30% below current levels of carbon emissions) by 2012. The Government has also set up the Low Carbon Vehicle Partnership to help promote the shift to low carbon vehicles and fuels, and a Bus Working Group comprising industry, academic and local authority interests is considering how to meet this target.

## Energy security

As a country, the UK has been a net exporter of energy, with significant imports and exports, for the past two decades following the successful development of North Sea oil and gas. For the future, the recent Energy White Paper[1] stated that UK oil and gas production will decline significantly over coming years and it is likely that the UK will become a net importer of gas on an annual basis by around 2006 and of oil by around 2010. By 2020 the UK could be importing around three-quarters of primary energy needs.

World-wide fossil fuel resources are very large. Oil is the world's most important fuel, accounting for 40% of global primary energy consumption. Its share in 2020 is likely to be at a similar level. Globally, conventional oil reserves are sufficient to meet projected demand for around 30 years, although new discoveries will be needed to renew reserves. Together with non-conventional reserves such as oil shales and tar sands, and improvements in extraction technology, there is the potential for oil reserves to last twice as long.

Proven gas reserves would meet at least 45 years of demand and there remains vast potential beyond this. That there is no shortage of oil and gas resources globally means that supplies are unlikely to be disrupted for long. But just as today, there will be risks of price shocks resulting from geopolitical disruption or damage to infrastructure in the short-term.

As the UK will become a net importer of gas within 3 years and oil within 7 years, the price in the UK will be set by the balance between demand and supply on a world wide scale. Demand has been rising steadily due to rising living standards whilst the supply is becoming increasingly constrained. This is due to the exhaustion of the big, older fields and the time and cost to develop smaller fields which are much more expensive to extract.

Recent predictions suggest that the world's oil production will peak around 2010 and thereafter decline at a rate of 3% per year whilst the total production of hydrocarbons (oil + gas and derivatives) could peak around 2015 and thereafter decline at a similar rate. The consequent mismatch between demand and supply will be reflected in both price and availability. Hence the operating economics of buses purchased today could change significantly over their asset life

It therefore becomes important for bus operators and local authorities to consider overall efficiency when purchasing new buses or refurbishing older vehicles. There is a need to be mindful of the longer-term issues surrounding oil supplies, and this partly explains the continued interest in seeking alternative fuels for transport and other end-uses.

## This guide

This guide provides recent information and practical examples of clean fuel buses in operation, using a wide variety of data sources, both in the UK and elsewhere in Europe. It aims to help overcome the barriers listed above by describing the pros and cons of clean bus operation, including a balanced and independent view of the economics and practicalities involved.

[1] 'Our Energy Future – Creating a Low Carbon Economy', Department of Trade and Industry, London, February 2003.

# Government Policy on Buses

## Transport 2010

The Government's framework for integrating buses with other transport was set out in 1999 in 'From workhorse to thoroughbred: A better role for bus travel', which was a subsidiary document to the White Paper 'A New Deal for Transport'. 'Transport 2010', the Government's 10-Year Plan for transport, was published in July 2000. The Commission for Integrated Transport (CfIT) has a remit to review and monitor progress towards objectives and targets set out in the 10-Year Plan and advise on the role of existing and emerging technologies, which will be important in terms of alternative fuels. Specifically in terms of buses and alternative fuels, the outcomes expected from the 10-Year Plan are:

- Better quality, less polluting, more accessible buses, with the average age of the bus fleet reduced to eight years by 2001 and speeding up introduction of low-emission vehicles;
- Improvements in air quality, noise pollution and the local environment, and reductions in $CO_2$ emissions.

The Plan envisages acceleration of the take-up of new, cleaner technology on road vehicles. It states that the Government will more than double its annual spending on cleaner vehicle initiatives by 2003/04. This will involve strengthening projects such as the PowerShift and CleanUp Programmes to encourage fleet managers to operate gas and electric vehicles, and to fit emissions reduction equipment to existing bus, taxi and lorry fleets. The Plan also states that support to encourage the early introduction of hybrid and fuel cell vehicles will be increased and the best use of economic and other measures to bring these technologies to the mass market will be reviewed.

## Powering Future Vehicles Strategy

As set out in the Powering Future Vehicle Strategy, the UK has a target that by 2012, 600 or more buses coming into operation per year will be low carbon, defined as 30% below current average carbon emissions. In order to encourage this, a group called the Low Carbon Vehicle Partnership Bus Working Group has been set up, to determine a baseline of current average emissions from buses. The Group have also provided recommendations to government on how best to encourage the take up of cleaner low carbon buses in the UK. Government has agreed in principle to these recommendations and will introduce a programme to encourage cleaner low carbon buses in the next year.

## Government Grant Programmes

The Government puts policy in to practice through a number of cleaner vehicle programmes. The PowerShift programme provides grants for the purchase of cleaner vehicles, while the CleanUp programme provides grants for the conversion and retrofitting of vehicles to reduce emissions, such as through the fitting of particulate traps. These programmes are funded by the Department for Transport and administered through the Energy Saving Trust through their TransportEnergy programmes.

## Bus Subsidy Review

The review of bus subsidies has been considering how the more than £1bn a year revenue funds DfT provides to support bus services in England could best be used to meet our objectives. These include increasing bus patronage and improving accessibility, as well as the environmental impact of transport. Improving bus services will help reduce congestion and pollution by encouraging more people to use buses rather than cars, and reduce social exclusion by providing better links to essential services for those who do not have access to cars. The review will not lead to any reduction in the amount of support provided. DfT is continuing this work in the context of the review of the 10-year transport plan. The results of the 10-year transport plan review will be announced in conjunction with the publication of the Spending Review in the summer of 2004.

# Emissions Reductions Technologies

Whilst switching to cleaner fuels is a solution to reducing emissions when replacing vehicles, there are also steps that can be taken to reduce emissions from the existing fleet through the fitment of emission reduction technologies such as particulate filters and exhaust gas recirculation. The TransportEnergy CleanUp programme offers grants for fitment of these technologies, provided they are listed on the CleanUp Register, which can be found on the TransportEnergy website at www.transportenergy.org.uk and following the links to CleanUp.

## Diesel Particulate Filter (DPF)

A DPF is a filter that is fitted in the exhaust pipe to reduce emissions of particulate matter. They are highly effective in reducing emissions of fine particles, but the necessary temperature required to regenerate the trap (burn off the trapped particles) is rarely achieved during low speeds such as in built up urban areas. Some traps raise the exhaust temperature by using fuel burners or electrical heaters whereas others lower the ignition point of carbon, either by using catalysts in the trap or by introducing a catalyst suspended in the fuel. A catalyst which is suspended in the fuel is stored in a small supplementary tank and would normally need to be refilled every 6-12 months depending on the vehicle's mileage – as a rule of thumb, about one litre of additive is used for every 2,000 litres of fuel.

Some manufacturers will not recommend fitting their DPF to older vehicles such as pre-Euro or Euro I, whereas others are more flexible, so check with different manufacturers as to what vehicles they can fit to. The duty cycle of the vehicle is also an important consideration when fitting a DPF, as unless the exhaust gases reach certain temperatures the trap may not function properly and the manufacturer may advise against fitting. Again certain manufacturers can fit traps to vehicles with low exhaust gas temperatures, and most will recommend that the exhaust temperature is checked beforehand (known as data logging) to ensure that trap will work effectively.

Fitting a DPF can reduce emissions of particulate matter, including ultrafine particles, by around 95%. A catalysed DPF can also reduce carbon monoxide (CO) and hydrocarbons (HC) by up to 80%. The cost of buying and fitting a DPF is normally between £3,000 and £5,000, but it will need to be maintained about twice a year depending on the duty cycle of the vehicle, which involves removing the ash residue on the filter.

## Diesel Oxidation Catalyst (DOC)

An oxidation catalyst consists of a stainless steel canister containing a honeycomb structure which is coated with precious metals. The metals are catalysts that chemically react with the exhaust pollutants to convert them into less toxic forms. This includes converting CO into $CO_2$ and oxidising the hydrocarbon component of the soot into water and $CO_2$.

DOCs can be very effective at reducing emissions from heavy duty vehicles, especially in older engines where a large percentage of the particulate matter consists of volatile components condensed onto the soot particle. The other advantage is that they can be fitted to any age of diesel vehicle and with any duty cycle, so are often a good solution where a trap is not suitable.

Fitting a DOC will reduce emissions of particulate matter from 20-50% and CO and HC emissions by up to 80% and usually costs £1,000 for a large commercial vehicle. In some cases, the exhaust system will need to be replaced, which will increase the cost. A DOC should not require any additional maintenance and there should be no change in fuel consumption, providing the system is properly engineered and maintained.

## Selective Catalytic Reduction (SCR)

SCR uses a reductant (ammonia or urea), which is injected into the exhaust gas to reduce NOx. Some systems also use a catalyst to improve the emissions reduction. SCR has been used for many years in large industrial processes, but only recently in vehicles. As it is an emerging technology there is less known about its performance compared to other technologies currently on the market. SCR can either be fitted on its own, or it can be fitted in conjunction with DOC or DPF.

An SCR system has the potential to reduce NOx emissions by between 30 and 70%, although this will be dependent on the duty cycle as the system is extremely temperature dependent. Some reduction in emissions of particulate matter is also usually obtained, even if a DOC or DPF is not fitted.

Fitting SCR to commercial vehicles over 7.5 tonne GVW may cost between £5,000 and £10,000. Exact costs of SCR are not yet available as many manufacturers are still developing their systems. Ongoing maintenance costs will involve regular replacement of the reductant, either ammonia or urea. The volume of urea consumed relative to diesel will depend on the size of vehicle, but is likely to be around 4-6%. Urea can also be bunkered on site and therefore makes refuelling more flexible.

## Exhaust Gas Recirculation (EGR)

EGR is a retro-fit NOx reduction technology that consists of a valve that uses the exhaust back pressure to recirculate exhaust gases back through the engine. The exhaust gas is introduced into the air inlet manifold of a normally aspirated engine or to the compressor inlet of a turbocharged engine. This reduces the peak combustion temperature and consequently the production of NOx emissions. Some EGR systems pass the air through a DPF to remove abrasive particles before recirculating it through the engine.

Fitting an EGR system can reduce emissions of NOx by around 40 to 50%. For maximum benefit, EGR should always be fitted with exhaust aftertreatment which would further reduce emissions of particulate matter, CO and HC. Fitting EGR to a diesel engine usually costs around £10,000 including the cost of an associated DPF.

## Repowering

Repowering or re-engining involves replacing an old engine with a more modern one to achieve better emissions performance from an existing vehicle. This can be expensive, but may be cost effective for buses which have a long service life.

Repowering can lead to reductions in emissions of all regulated pollutants, lower fuel consumption and improved reliability, although this can vary significantly from case to case. As an example, replacing a pre-Euro diesel engine in a bus with a Euro II engine, or a Euro I engine with a Euro III, could lead to reductions in emissions of around 60% for particulate matter and 40% for NOx. It is also recommended to fit a DPF at the same time in order to further reduce emissions. Alternatively, the diesel engine could be replaced with one which runs on gas which would provide even lower emissions.

Fuel economy should improve by up to 6% when replacing a pre-Euro with a Euro II engine, if the equipment is carefully matched (this may require a revised drive-train). Replacing a Euro I with a Euro III engine may however increase fuel consumption by up to 5%. A modern diesel or gas engine will also be quieter than the older diesel engine and cause less vibration.

It is important to remember that replacing the engine in a particular vehicle may not produce these emission reductions and improved performance if the characteristics of the new engine do not match the characteristics of the existing vehicle (in terms of rated speed, power and torque characteristics). It may therefore be necessary to install a new transmission as part of an integrated package.

Typical costs for repowering to Euro III with a heavy duty diesel engine are around £10,000 to £15,000. This cost will increase if the transmission is also replaced, which is recommended since it will optimise performance and longevity. In many cases changes will also need to be made to the intake, exhaust, cooling and electrical systems.

Even though the majority of vehicles in the UK operate on petrol or diesel, the market for cleaner fuels and technologies has significantly expanded in recent years. This brings increased opportunity to the bus industry and services providers when seeking to purchase and test innovative schemes. From an emissions point of view, the technology is now available for meeting local, national and international standards. It is the other issues such as operating costs, providing valuable technical support for the vehicles and forming robust relationships between manufacturer, operator and local authority that require more effort.

## Enhanced conventional fuels

### ULSD

Ultra Low Sulphur Diesel (ULSD) has accounted for around 100% of the diesel market since 1999. It has a maximum sulphur content of less than 50ppm and will be mandatory to use from 1 January 2005. ULSD can result in particulate reductions of up to 40% when compared to previous diesel fuels. The low sulphur content also offers the potential for using other technology to further reduce emissions, such as oxidation catalysts and particulate traps, which can cut emissions of $PM_{10}$ by up to 90%.

#### Emulsion fuels

This involves blending purified water with diesel fuel to form an emulsion with a milky appearance. There is currently only one product on the market – Lubrizol's PuriNOx™ which is marketed by BP in the UK. Claimed benefits include improvement of combustion that leads to considerable reductions in $PM_{10}$ (up to 25%) and smoke (up to 80%). Lower combustion temperatures can also reduce NOx by up to 15%. These emission reductions should be treated as average values – the actual reduction achieved is heavily dependent on the individual design of the combustion chamber and fuel pump in the vehicle concerned. No engine modifications or retrofit components are necessary in order to use the fuel in conventional diesel engines, but there may be a slight reduction in performance and an increase in the volumetric fuel consumption due to the water content of the fuel. Some trials of water emulsion diesel have shown a reduction in $CO_2$ emissions of between 3% and 12% compared to diesel. Although fuel consumption increased due to the water content, this was not proportional to the amount of water in the fuel, therefore leading to a reduction in $CO_2$.

***More information***

Appendix 1 provides more details on other information sources relating to clean fuel vehicles. For information on PuriNOx™, see ***www.lubrizol.com***

## Liquefied Petroleum Gas

Liquefied Petroleum Gas (LPG) is mainly a mixture of propane and butane. In the UK LPG contains over 90% propane by weight. LPG is a by-product of oil refining and is also found as an associated liquid gas in natural gas fields. It has been used as an alternative fuel in the transport sector for over 60 years. There are currently over 8 million road vehicles using LPG around the world, with significant numbers in Italy, the Netherlands, and North America. In the UK there are over 90,000 LPG vehicles in use on the road, mainly comprising cars and light vans.

LPG has the advantage of being composed of simple chemical compounds which can easily form a homogeneous mixture with air. As a result LPG has a higher motor octane number than petrol (by about 5-10%), especially if the propane content is high. This allows a more complete combustion in vehicle engines than is the case for petrol, and higher engine compression ratios can be used, thereby improving fuel consumption. Simple conversions based on existing designs of petrol engines and petrol/LPG bi-fuel systems cannot take full advantage of this characteristic, but modern conversions with electronically controlled gas injection systems or liquid injection offer performance comparable to that of petrol engines.

LPG has a lower energy density by volume than conventional fuels – typically about one-third less than for petrol (23.6MJ/litre as compared with 32.3MJ/litre). This means that a greater volume of fuel is required. However, by mass, LPG contains around 8% more energy, and hence less fuel mass is required for a similar vehicle range. LPG is usually stored as a liquid under moderate pressure of between 4-12 bar. This allows the gas to be stored and transported in lightweight pressure vessels, but these weigh more and require more volume than the equivalent storage for petrol in an on-board fuel tank.

The cetane number of LPG is too low for proper self-ignition in a compression ignition engine. Heavy duty vehicles which operate on LPG do so using either:

- LPG stoichiometric engines, based on a spark ignition engine, with the LPG either added to the air flow or injected in gaseous or liquid form;
- LPG lean-burn engines, which allow a significant improvement in fuel consumption as well as increased engine efficiency.

Most types of vehicle can be built, or converted, to run on LPG. Vehicles can be set up to run either as 'mono-fuel' vehicles which have LPG as their only fuel and are spark ignited – like petrol, or as 'bi-fuel' vehicles. These are vehicles which can operate on both petrol and LPG; the change from one fuel to the other taking place at the flick of a switch. Some motor manufacturers are now offering bi-fuel vehicles as standard products. The conversion of a petrol engine to run on LPG, having spark ignition, is relatively simple and low cost, and LPG has proved popular as a fuel for cars and vans.

LPG can offer significant benefits in reducing particulates and NOx compared with diesel engines, and whilst the differential may be reduced, can continue even as tighter emission standards come into force and new emission control technologies are used in conventionally fuelled vehicles. However, LPG offers fewer air quality benefits in comparison with petrol. Lifecycle emissions of greenhouse gases from LPG vehicles are better than equivalent petrol vehicles, partly due to the vapour retrieval on tank filling. $CO_2$ emissions can be comparable with diesel vehicles. LPG engines operate at lower noise levels than diesel engines.

Operational costs, excluding fuel, have proved to be lower than other alternative fuels such as CNG, and close to conventional diesel operation. LPG has been at the forefront of alternative fuel take-up in cars, and the current retail price per litre (approximately half the price of petrol due to the current favourable tax regime) makes it a strong contender for fleet operators when considering the operational costs of running cleaner fuels. The Government is, however, consulting on the future of fiscal incentives on all road fuel gases and will announce the results in its 2003 Pre-Budget report in November 2003. The practicality of converting existing diesel engines to run on LPG is more difficult than compared to petrol vehicles – an issue therefore for buses, although diesel to LPG conversions are available for black cabs and are currently funded under TransportEnergy's CleanUp programme. There are more than 1,200 retail sites across the UK offering LPG. For more information about the locations of sites see www.lpga.co.uk and www.transportenergy.org.uk

## Natural Gas

Natural gas is predominantly methane, mainly found in underground (or undersea) fields and often associated with oil. There are almost 1.5 million natural gas vehicles in use around the world, with Argentina, Italy, and Russia having large fleets, due to cheap local supplies of gas. There are currently fewer than 1,000 natural gas fuelled vehicles in the UK. Natural gas may vary in composition, which may affect its performance as a vehicle fuel. Natural gas has a high octane rating, and being a gas it requires no vaporisation and hence mixes easily with air prior to combustion. This offers lower idling speeds, better performance and easier cold starting, and a more complete combustion which all help to reduce exhaust emissions. Lean-burn operation is feasible with natural gas.

Natural gas vehicles can be set up to run either as 'mono-fuel' vehicles which have natural gas as their only fuel and are spark ignited – like petrol – or 'dual-fuel' vehicles which burn diesel and natural gas together in the engine. Dual-fuel engines cannot switch between fuels like petrol bi-fuel engines, although they can run solely on diesel if required. Mono-fuel vehicles will usually offer the best combination of emissions, performance and efficiency. However, until a public refuelling infrastructure is developed, mono-fuel vehicles will normally have to return to their depots to refuel, so in certain circumstances, dual-fuel vehicles will be the most practical solution. The dual fuel system provides a gas/air mixture which is ignited by a small injection of diesel fuel. Gas provides between 0 and 90% of the fuel depending on operating conditions.

Natural gas has proved popular as a fuel for trucks, buses and larger vehicles in countries where tax incentives have been available. The extra weight and cost of on-board fuel tanks makes conversion to natural gas normally more expensive than LPG for smaller vehicles. Some UK manufacturers are now offering dual-fuel vehicles as standard products with a number of mono-fuel fuel products available, particularly amongst the heavier vehicle options. Most types of vehicle can be built, or converted, to run on natural gas.

To get sufficient volume of energy into a conventional size fuel tank requires that natural gas be compressed, or cooled to liquefy it. In all cases, gas is stored on the vehicle in special fuel tanks; it is then piped to the engine via special high pressure pipes and introduced into the engine intake tract, controlled by a regulator. Natural gas is normally stored on-board the vehicle in a high pressure cylinder at about 200 to 250 bar (around 3,000psi), and in this case the fuel is termed compressed natural gas (CNG). The weight of fuel and tank will typically be about 4 times heavier than the equivalent petrol or diesel storage tank filled with fuel. A car would typically have a single cylinder of around 90 litres capacity (16kg gas, equivalent to around 5.2 gallons of petrol).

The other alternative is to cool the natural gas to a very low temperature so that it forms liquefied natural gas (LNG). This fuel is stored in smaller, vacuum insulated fuel tanks to maintain the low temperature required at around -60°C. High energy concentration is achieved in LNG, one litre of which vaporises to give over 600 litres of natural gas at ambient temperatures. The fuel is contained at comparatively low pressure (30-150psi, compared to 3,000psi for CNG), and therefore the weight of the tank is significantly lower than that of a CNG cylinder of comparable volume. Although LNG has increased costs and handling problems compared with the more established CNG, LNG substantially increases storage efficiency, which results in around three times the vehicle range compared with CNG operation.

Compared to existing diesel vehicles, mono-fuel natural gas engines offer air quality benefits in reductions of particulate matter and NOx by up to 80% and 95% respectively, but usually involves a small increase in lifecycle greenhouse gas emissions. Compared with a diesel engine using a particulate trap, the difference in particulate emissions between natural gas and diesel is however small. Methane emissions can also increase from natural gas engines, but this is usually controlled through fitting a catalyst. Natural gas engines are also less noisy than diesel engines, as it involves a switch from a compression engine to spark ignition engine, resulting in a noise reduction of around 10dBA which is a perceived halving of noise levels. As more stringent emissions standards are introduced for diesel, most notably the Euro IV standards from 2005, and the use of exhaust after-treatment devices such as particulate traps become more widespread, the margin in particulate matter emissions between diesel and natural gas may decline. The cost of installing a depot based natural gas refuelling site ranges from around £250,000 to £500,000 for CNG, and around £100,000 to £300,00 for LNG. The TransportEnergy PowerShift programme does however provide grants of up to £100,000 towards the cost of installation, provided there is third party access to the site.

For more information about natural gas as a vehicle fuel see www.natural-gas-vehicles.co.uk and www.iangv.org.

## Liquid Biofuels

Liquid biofuels produced from biomass sources are potentially capable of providing minimal net (lifecycle) emissions of carbon dioxide. This is due to the renewable nature of the fuel, and the absorption of carbon dioxide during cultivation of the biomass crop. Biodiesel is the most developed of the liquid biofuels, but other vehicle fuels can be obtained from biomass sources including biomethanol and bioethanol.

Biodiesel can be produced from a range of vegetable oils, including rapeseed, palm, sunflower and soyabean oils. Oilseed rape is one of the main oilseed crops grown in the UK, and is the most likely feedstock for biodiesel production. Biodiesel from oilseed rape is also known as rape methyl ester (RME). Around 700,000 tonnes of biodiesel are produced each year in Europe, mainly in Austria, France, Germany, Italy and Spain. Biodiesel can also be sourced from waste vegetable oils which provide a useful outlet for these oils which may otherwise be poured away into landfill sites. However the waste oils have to be collected and cleaned before they are esterified into biodiesel and this imposes an additional cost. The production potential of biodiesel in the UK is about 1.45t per hectare of oil seed rape. The technology to produce biodiesel is proven and commercial production is being planned by several UK companies.

Biodiesel can be used in existing diesel engines without modification, replacing mineral diesel, or it can be blended with diesel in varying quantities. Blending is common in France where 5% blends are used, and is now the standard blend that is likely to be used in the UK. The physical and chemical properties of biodiesel are very similar to diesel. It is slightly corrosive to hoses and some paints, but alternatives are available at low cost. Engine performance is not affected when using biodiesel, but a 5% greater volume of biodiesel is needed to maintain vehicle performance and range relative to diesel since the energy density of biodiesel is lower. There may be odour problems associated with biodiesel combustion from some sources, such as vegetable oils.

No modification is required to the engine or the vehicle unless permanently running on 100% biodiesel. NOx emissions are likely to increase with 100% pure biodiesel. Hence, the limitations imposed by the use of compressed gas storage tanks or electric batteries – reduced load capacity and/or vehicle range – do not apply. In the UK most motor manufacturers are normally content to maintain warranties when using a 5% biodiesel blend, and will often issue a letter of no objection. This should be checked with the manufacturer before using biodiesel to make sure it is the case.

Biodiesel – whatever the feedstock – generally provides few air quality benefits relative to ultra-low sulphur diesel, in terms of tailpipe particulate and NOx emissions. However, the exact emission performance of biodiesel as a blend can vary depending on the type of diesel vehicle and fuel specification, and further testing work is required before the emissions benefits can be fully quantified. Depending on the feedstock used, biodiesel can provide a small reduction in greenhouse gas emissions on a life-cycle basis, up to around 3%. Most greenhouse gas emissions from biodiesel derived from oilseed rape occur during the cultivation of the crop, which requires the use of agricultural machinery and the application of fertilisers and pesticides. Greenhouse gas emissions from the use of biodiesel derived from recycled vegetable oil depend on whether the vegetable oil is otherwise recovered and used in animal feed or whether it is disposed of as a waste product. In the latter case, conversion into biodiesel would provide a useful and sustainable alternative disposal route.

Biodiesel production is being developed by several fuel suppliers, and 5% biodiesel blends are available at several

**More information**

For further details about biodiesel and biofuels in general, see ***www.biodiesel.co.uk*** and ***www.biofuels.fsnet.co.uk***

retail outlets across the UK. At the time of writing this guide (summer 2003), almost 100 retail sites were offering biodiesel blends. For more information about site locations see www.biodieselfillingstations.co.uk

Biodiesel that meets certain emissions standards and complies with EN14214 and EN590 standards qualify for a fuel duty of 20 pence per litre less than ULSD. It is only the biodiesel component of blended diesel that qualifies for the reduced duty rate, so for a 5% biodiesel and 95% mineral diesel blend, only 5% will be eligible for the reduced fuel duty. Biodiesel is also eligible for a 100% rebate under a Bus Service Operators Grant.

## Energy efficient drive lines

Current bus fuel economy is about 50 litres/100 km in stop/start urban traffic. Most increases in efficiency over the past 20 years have been counteracted by increases in bus weight, providing additional passenger comforts like climate control and reducing local pollutants.

However technology has existed since the 1978-1980 oil crisis capable of improving the overall drive-line efficiency by at least 30%. In the intervening 20 years the technology has been further enhanced and this technology is now ready for exploitation. Improvements in drive-line efficiency will benefit local air quality and reduce emissions of greenhouse gases. These benefits are further enhanced by selecting the most efficient power source.

The key technological advances are:

- Drive-by wire using micro-processor control;
- Transmissions which can match torque required to available power;
- Drive-lines in which power can flow both ways thus allowing braking energy to be recovered;
- Reduction in size and cost and improvement in performance of semi-conductor power devices;
- High speed motors and generators;
- Precision moulding of fibre reinforced plastic components with high strength to mass.

There are three principal solutions which utilise some or all of these technologies:

- An all-mechanical drive-line using a continuously variable transmission (CVT) rather than an automatic transmission to provide better control between speed and torque;
- An electric drive-line with a small diesel (or internal combustion engine) driving an electric generator;
- An electric drive-line with the battery as the power source with a motor either driving a rear axle or a wheel mounted (hub) motor.

The gains in efficiency can be very substantial ranging from 15% for the CVT to 50% for an all-electric drive-line. Additional gains in efficiency of about 20% can be achieved by storing the inertial energy of the vehicle on slowing down or stopping and reusing when accelerating. This is achieved because up to 50% of bus energy use in urban areas is consumed in accelerating the vehicle. The gains in air quality result from operating the internal combustion engine or battery pack in its most efficient regime for a greater period of the time. The overall improvements in air quality can be substantial both in terms of local and global pollution with a reduction in $CO_2$ emissions of between 30% and 75%. The exact values will depend upon the drive-line configuration and size. These concepts have now been proven and the next step is to demonstrate the reliability, maintainability and economics of pre-production components in service trials. Energy efficient drive-lines are characterised by a higher initial and lower running cost than normal drive-lines. The payback time has yet to be demonstrated and is very dependent upon the level of fuel duty rebate. With the present regime, initial calculations suggest a possible 5 to 10-year pay back time.

## Infinitely Variable Transmission (IVT)

Defining gear ratio as **input speed/output speed**, and a transmission that has clutches engaged, and yet has zero output speed for a range of input speeds, has an infinite ratio. If, in addition, it has a variable ratio element, it can be said to be Infinitely Variable. One way of achieving this to use an epicyclic shunt to sum engine speed and variator output speed. Current bus automatic transmissions use a torque converter as a starting device. The epicyclic shunt IVT reduces power losses by approximately 15% when moving off, compared to conventional automatics[2]. In addition, the IVT allows input speeds up to their maximum while the vehicle is at rest, thus opening a technology gateway to the use of flywheel energy storage units in a mechanical driveline, which can save an additional 15-30% in energy consumption. Torotrak (Development) Ltd have run prototypes in 6 tonne sport utility vehicles that show 13-17% fuel economy advantage – small buses could use the same basic transmission. 16-24 tonne bus transmissions could follow.

[2] 'Comparison of CVT starting device effectiveness', by Chris Greenwood, Mervyn Patterson and Phil Winter, Autotech UK C462/13/112

## Electric vehicles

Electricity can be delivered to buses by means of overhead catenary/wire systems, by on-board batteries or by electricity generated on the vehicle itself. Currently, the most common form is to use electrical energy from battery storage. When required, electricity is drawn from batteries and converted to motive power by the use of an electric motor. In a battery electric vehicle (BEV) the conventional fuel system is completely replaced by batteries and an electric motor. Vehicles may be derivatives of standard production models or purpose-built. Electricity is most suited for use in city-based cars and vans with set journey patterns requiring a limited daily range (up to 80km), though it has also been tested in some urban buses. Excluding specialist electric vehicles such as milk floats and off-road vehicles, there are around 600 electric vehicles, mainly passenger cars and vans, in the UK. BEVs are commercially available from a small number of motor manufacturers. The reduced range possible from battery-operated vehicles is no less significant for buses, especially in urban environments where stop-start activity can drain battery technology. With no internal combustion engine (ICE), issues also arise from the fact that heating, air conditioning and cabin fan controls put extra demand on the battery capacity.

The weight of the battery is in itself significant and reduces potential passenger carrying capacity. Batteries are expensive and have a relatively short life compared with the vehicle itself. Nevertheless, electric buses have been proven to provide emission-free transport at the point of use on the roads.

Electric buses have been operated since 1996 in Uppsala and are used in a number of northern Italian towns. Typical buses are 8 to 9m in length with low floor throughout the bus and the battery and drive-train mounted transversely at the rear. They are used on inner city routes where there is a need to improve air quality locally and reduce engine noise and vibration. The ride is good because the electric motor provides a continuously variable speed and the buses are popular with both drivers and passengers.

The economics of such buses is dominated by the need to replace the battery pack during the day to obtain the necessary range and to replace the battery packs every 2 to 3 years. The current lack of buses above 9m is due to the size and mass of the battery pack necessary to accelerate such vehicles from rest. In addition to changing the battery during the day, there are three technical options for extending the range:

- Storing the inertial energy on slowing down and stopping in a power storage unit – this energy can then be reused when accelerating reducing the demand of current from the battery – such storage systems include mechanical systems (like flywheel), hydraulic and electrical (supercapacitors) – flywheels are the system with the most operating hours to date;
- Recharging the battery from an external power source at bus stops and depots;
- Using a small diesel (or internal combustion engine) to drive an electric generator to continuously recharge the battery.

An alternative option is hybrid electric vehicles (HEV). These vehicles use a combination of a fossil fuel and electricity. The electric energy system is used at lower speeds and for stop-start driving in urban areas. The fossil fuel is combusted in a conventional internal combustion engine and is used either to drive the vehicle directly outside urban areas, or to travel at higher speeds, or to recharge the batteries. Series-hybrids are vehicles which use an internal combustion engine to generate electricity which is then delivered to the wheels via electric motors. Parallel-hybrids can be powered mechanically or electrically, either by an internal combustion engine or a battery motor system. Switching fuels in this way enables the operator to reduce emissions, especially in urban areas.

A promising low carbon technology for buses is based on a 'hybrid-electric' drive train which has the potential to improve fuel economy and hence carbon dioxide ($CO_2$) emissions between 30-50%. The hybrid vehicle can offer zero tailpipe emissions at especially stop-start and slow speeds. The ICE is used for the majority of traction that would otherwise drain the battery in the case of an electric motor. Other alternative fuels such as CNG can be used as well as diesel. Demonstrations and vehicles in actual service have recently operated, for example, in Europe and the US.

It is important to consider the source of electricity used in electric vehicles. A mix of nuclear and fossil fuels, together with renewable energy (hydro, wind and biomass) is used by the UK electricity supply industry for electricity production. Greenhouse gas and other emissions from fossil fuelled power stations contribute to climate change, whereas nuclear and renewable sources of electricity have low or zero emissions of greenhouse gases. Present UK policy envisages that 10% of electricity supply will be from renewable sources by 2010.

**More information**

For greater detail on fuel characteristics, issues, availability, application and benefits, the SMMT's ***Future Fuels Report*** (March 2002) is a good source.
Alternatively, the EST's ***Pathways to Future Vehicles*** study (April 2002) also provides summaries.

## Effects on passenger capacity and capital costs

The effects of using the currently available alternative fuels on the passenger carrying capacity are listed in Table 1. Compared with diesel-fuelled vehicles, most clean fuels impose a weight and volume penalty due to the fuel tanks required to give an operating range similar to conventional fuels.

*Table 1:* **Effects on passenger capacity**[3]

| Fuel | Fuel tank capacity (litres) | Storage pressure (bar) | Extra weight for 500km range | Passenger capacity reduction |
|---|---|---|---|---|
| **Diesel/biodiesel** | 200 | 1 | – | – |
| **LPG** | 600 (roof or chassis mounted) | 4-10 | 250kg | 0-3 persons |
| **CNG** | 1300 (roof mounted) | 200 | 1200kg (steel) 800kg (composite | ~6 persons |

The capital cost of a standard 12m bus is around £100-120,000. The extra capital costs of alternative fuelled buses range from around £25-30,000 for dedicated LPG or CNG buses. This differential could reduce with higher production volumes of such vehicles.

## Fuel duty

The Government has used fuel duty rebates as one means of encouraging the uptake of clean fuels in the broad transport fuels market. Table 2 lists the current and future rates of road fuel duty for ultra-low sulphur fossil diesel and petrol, the road fuel gases (ie. LPG and CNG) and biodiesel. From 1 September 2004, the Government will introduce a new rate of duty for sulphur-free petrol and diesel, set at 0.5 pence per litre lower than the rate for ultra-low sulphur fuels. This will encourage the early introduction and take up. From 1 January 2005, the Government will also introduce a new rate of duty for bioethanol, set at 20 pence per litre below the rate for sulphur-free petrol.

The Government will be consulting stakeholders on ways to ensure that fiscal incentives and other policy measures for road fuel gas continue to reflect the Government's environmental and other policy objectives, with a view to announcing decisions on future means of Government support.

*Table 2:* **Fuel duty rates**

| Fuel type | Duty from April 2003 | Duty from October 2003 |
|---|---|---|
| **Ultra-low sulphur diesel/petrol** | 45.82p/litre | 47.10p/litre |
| **Road fuel gases** | 9p/kg | 9p/kg |
| **Biodiesel** | 25.82p/litre | 27.10p/litre |

The current system of fuel duty rebate (now called Bus Service Operators Grant – BSOG) is paid directly to bus operators according to how much fuel they use. It refunds around 80% of the duty paid on ultra-low sulphur fuels, and there is a 100% rebate for gas-powered buses. The system does not support the use of fuels such as LNG or the use of emulsion based fuels. During 2003, the Government has been reviewing the bus subsidies system as a whole, including the role of BSOG. Any changes to the system may have an impact on the relative attractiveness of alternative fuels for bus operators.

## Reduced Pollution Certificates

Buses which meet certain emissions standards may be eligible for a Reduced Pollution Certificate, reducing the Vehicle Excise Duty paid by the operator. They do not apply if an alternative, more costly fuel such as water-diesel emulsion, or a fuel borne catalyst, are used in an otherwise standard vehicle.

[3] Source: Report of the alternative fuels group of the cleaner vehicles task force, DTI, March 2000

# Environmental Performance

## Emissions standards

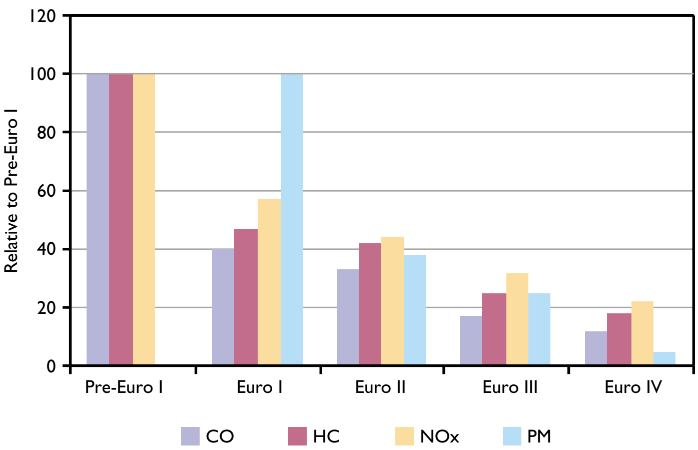
Emissions standards for road vehicles have been made progressively more stringent by European legislation over the last 10-15 years. Pollution from buses and coaches is falling as a result of high levels of investment in new vehicles and tighter emissions standards. New buses and coaches placed in service since October 2001 must comply with Euro III emission standards, which improve by over a third on the 1993 standards. The emission limits are shown in Figure 1 and Table 3.

*Table 3:* **Legislative Limits for Heavy Duty Vehicles/Buses (g/kWh)**

| | CO | THC | NOx | PM | Test cycle | Implementation |
|---|---|---|---|---|---|---|
| **Pre-Euro I** | 12.3 | 2.6 | 15.8 | - | ECE R49 | 1 April 1991 |
| **Euro I** | 4.9 | 1.23 | 9.0 | 0.4 | ECE R49 | 1 October 1993 |
| **Euro II** | 4.0 | 1.1 | 7.0 | 0.15 | ECE R49 | 1 October 1996 |
| **Euro III** | 2.1 | 0.66 | 5.0 | 0.10 | ESC | 1 October 2001 |
| **Euro IV** | 1.5 | 0.46 | 3.5 | 0.02/0.03 | ESC/ETC | 1 October 2006 |
| **Euro V** | 1.5 | 0.46 | 2.0 | 0.02/0.03 | ESC/ETC | 1 October 2009 |
| **EEV** | 1.5 | 0.25 | 2.0 | 0.02 | ESC/ETC | Not yet agreed |

THC = Total hydrocarbons
PM = Particulate Matter
ESC = European Steady State Cycle; ETC= European Transient Cycle
EEV = Environmentally Enhanced Vehicles (Legislation pending)

*Figure 1:* **Emission limits for new heavy diesel engines**[4]




### Analysis of bus emissions across fuel and vehicle type

Despite the industry and government having conducted in-service trials and emissions tests in recent years, good quality data that are specific to bus operations in the UK are relatively sparse. Several government programmes, in other parts of Europe, North and South America and Australia, have provided reports and information on emissions, operating experience, costs and maintenance and reliability. Some of the information in these reports is relevant to the UK, but national differences in, for example, grant schemes, fuel duties, and infrastructure availability, mean that comparisons cannot always easily be made with the UK. For example, data are available from US sources, such as the US Department of Energy Alternative Fuels Data Centre (www.afdc.nrel.gov), but most information on buses in the database relates to operations in North American cities. The International Energy Agency also produces information on alternative fuels in public transport vehicles through their CADDET database (www.caddet-re.org). In addition, the report of the Alternative Fuels Group of the Cleaner Vehicle Task Force gives some bus data.

The following points should be stressed when considering emissions from clean buses:

- The variation of data type/format that exists is extensive;
- Data are derived from different test facilities (from the UK and abroad);
- Drive-cycles employed to test vehicles are different;
- Emissions vary between those vehicles tested under steady-state and those exposed to real-world driving conditions;
- Testing a vehicle on a dynamometer test bed is unlikely to reproduce the real-world conditions experienced on urban streets;
- Real-world conditions experienced on UK urban roads have been found to vary considerably to those even in the rest of Europe;
- Different vehicle models using the same fuel can show different emissions results.

It should also be recognised that the diesel engine has been the subject of many years' development, whereas many alternative fuels are still in the early stages of development.

One of the most useful sources of data on clean bus emissions

[4] There was no specific standard for PM emissions in the pre-Euro I legislation.

*Table 4:* **Comparative emissions for different fuelled buses (g/km)**

| Fuel type | Reference vehicle | CO | NOx | THC | PM | $CO_2$ | Fuel economy (litres/100km) |
|---|---|---|---|---|---|---|---|
| **Diesel Euro II** | Volvo Olympian | 1.35 | 15.0 | 0.64 | 0.23 | 1386 | 51.14 |
| **City diesel** | Volvo Olympian | 1.38 | 14.2 | 0.64 | 0.157 | 1351 | 50.83 |
| **City diesel + CRT** | Volvo Olympian | 0.21 | 12.53 | 0.143 | 0.028 | 1343 | 50.37 |
| **LPG dedicated** | DAF GG 170 | 0.013 | 5.4 | 0.027 | 0.017 | 1309 | 85.84 |
| **CNG dedicated** | Volvo B10L single deck | 0.66 | 9.92 | 3.01 | 0.05 | 1343 | 49.94 (kg/100km) |

and operation in the UK is the Cleaner Vehicles Task Force report of March 2000[5]. Table 4 displays data from a range of buses which have been tested by Millbrook on the simulated London bus route. The diesel vehicles displayed are also only representative of Euro II technology, whereas current technology would need to satisfy Euro III standards. The "City diesel" used in these tests is equivalent to the current ULSD fuel grade which is now available. Low sulphur diesel allows the use of the continuously regenerating trap (CRT) which offers a method of reducing particulates to levels well below Euro IV standards.

Table 5 shows data from a study by Sciotech[6] and illustrates the role of electric hybrid vehicles in encouraging zero regulated emissions. The application of a flywheel goes towards further reducing the levels of electric power needed to recharge batteries and therefore $CO_2$ derived from power production.

*Table 5:* **Electric hybrid vehicle (g/km)**

| | *Emissions Type* | | | | |
|---|---|---|---|---|---|
| Fuel | CO | HC | NOx | PM | $CO_2$ |
| **Euro II Diesel (using ULSD + CRT)** | 0.202 | 0.138 | 11.9 | 0.022 | 1.281 |
| **CNG with CRT** | 0.66 | 3.01 | 9.92 | 0.05 | 1.344 |
| **LPG with CRT** | 0.132 | 0.027 | 5.4 | 0.017 | 1.309 |
| **Electric hybrid (battery plus flywheel)** | 0 | 0 | 0 | 0 | 0.025* |

One of the latest vehicles to undergo testing in the UK is the 'Electrocity' manufactured by Wrightbus[7]. Table 6 shows emission comparisons between the electric hybrid vehicle and Euro III and IV standards. The manufacturer claims to significantly reduce all emission levels when compared to Euro III. The zero level for HC is representative of when the bus is operating in electric mode only. Further details of the performance of this vehicle are given in Section 4.

*Table 6:* **Electrocity emissions compared to Euro III & IV requirements (g/km)**

| Emission type | Electrocity** | Euro III*** transient emissions | Euro IV*** transient emissions | Improvement for Electrocity as % of Standard | |
|---|---|---|---|---|---|
| | | | | Euro III | Euro IV |
| **HC** | Zero | 0.78 | 0.46 | 100% | 100% |
| **CO** | 0.24 | 5.45 | 4.00 | 96% | 94% |
| **NOx** | 0.48 | 5.00 | 3.50 | 90% | 86% |
| **PM** | 0.03 | 0.16 | 0.03 | 81% | Equal |

## Well-to-wheels emissions

In recent years, there have been many studies of the life-cycle of transport fuels. Such 'well-to-wheels' studies have generally aimed at identifying the energy use and greenhouse gas emissions associated with each stage of the life-cycle of various fuels, and thereby producing comparisons between different fuel types of the energy and environmental impacts of the complete life-cycles.

The life-cycle comprises essentially the production and transport of the feedstock, followed by the processing, manufacturing and transport of the vehicle fuel to the retail distribution outlets. The complete life cycle includes the final use of the fuel in the vehicle through combustion in an internal combustion engine. Key issues in these various studies are the differing methodologies, and differing energy and emissions assumptions regarding the boundaries of the fuel production and utilisation processes. Other differences occur in the ways in which processing and production energy use is allocated to the particular fuel under investigation.

[5] Cleaner Vehicles Task Force: 'An assessment of the emissions performance of alternative and conventional fuels', DTI, London, 2000
[6] Sciotech: 'Transforming the market for electric vehicles for use on public transport', University of Reading, 2002.
[7] Source: Wrightbus (www.wrightbus.com)

*Assuming electricity consumption of 1kWh/km.

** Actual emissions for Electrocity (g/km tests on Millbrook 159 London Bus Route).

*** Euro III and IV standards for internal combustion low sulphur diesel buses.

Table 7 shows qualitative estimates for the emissions of regulated pollutants and $CO_2$ for heavy duty vehicles for several different fuels relative to ultra-low sulphur diesel[8]. The data cover quite a wide range and can be considered as illustrative only, but they can be used as a broad brush comparison between the life-cycles of these fuels.

*Table 7:* **Heavy duty vehicles emissions along the fuel chain – relative to diesel**

| Fuel | CO | HC | NOx | PM | $CO_2$ |
|---|---|---|---|---|---|
| **Diesel** | 100 | 100 | 100 | 100 | 100 |
| **LPG** | 40 | 10 | 0 | 10 | 95 |
| **CNG** | 60 | 50 | 400 | 15 | 90 |
| **BEV** | 0 | 0 | 0 | 0 | 70 |
| **Diesel-Hybrid Electric Vehicle (with particulate trap)** | 20 | 160 | 10 | 15 | 75 |

## Driver Behaviour

It should be noted that one of the most important factors in determining emissions and energy use in bus operation is the way in which the vehicle is driven. Good driving habits, by making best use of the vehicle gearbox, braking and handling, will reduce fuel consumption and thereby reduce emissions. Driving in congested, stop-start conditions will incur higher fuel consumption, whereas steady state operation at optimum speeds will have lower fuel consumption. This also illustrates the point that comparisons of emissions and performance between different fuels need to be made only on the basis of directly compatible test cycles, with the vehicle operating conditions being as closely similar as possible from one fuel to the next.

[8] Sources: 'Automotive fuels for the future', International Energy Agency, Automotive Fuels Information Service, Paris, 2000; and Report of the alternative fuels group of the cleaner vehicles task force, DTI, March 2000.

# Current Experience with Cleaner Fuel Buses

## Bus operation in urban areas

In 2002, over 98% of UK buses operated on diesel fuel. The fleets of each of the three largest bus companies have been converted to run on ultra low sulphur diesel, which reduces sulphur emissions by 90%. This also enables the buses to achieve a 30% reduction in smoke emissions and cut particulate emissions by 18%. Appendix 2 provides more information about the UK bus industry.

At present, alternative fuelled vehicles represent only around 0.2% of the UK bus fleet. However a number of Local Authorities and operators are field-testing alternative fuelled buses and several bus operators have now introduced LPG buses into their fleets and in particular 'Quality Partnerships' between bus operators and local authorities can provide a basis through which alternative fuelled buses can be introduced[9]. Appendix 3 outlines relevant legislation in more detail.

The Bus Service Operators Grant (also known as Fuel Duty Rebate – FDR) has acted as the main perceived barrier to the introduction of cleaner fuel vehicle within bus fleets. As illustrated in Figure 2, market research carried out by EST, involving a survey of 100 bus and coach companies, revealed that FDR is one of the major barriers quoted to switching to alternative fuels[10]. It should be noted that the market research did not examine views on the reliability, and the capital and maintenance costs of cleaner buses, which could also form barriers to their use.

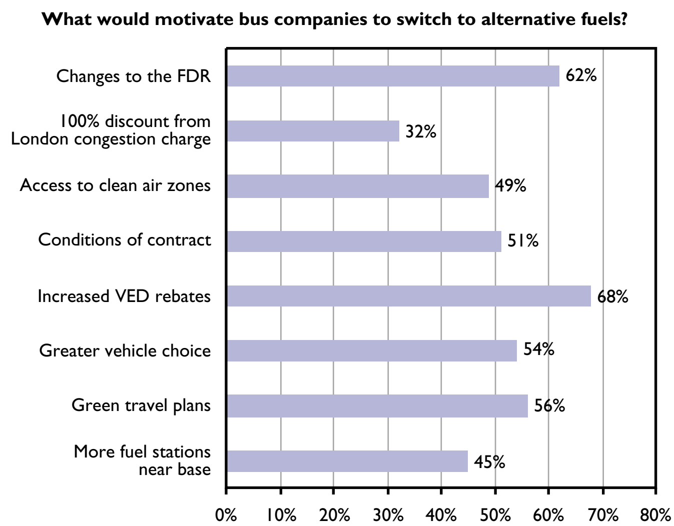



*Figure 2:* **Motivation to switch to alternative fuels**

The effects of FDR are that bus fares are lower than they otherwise would be, and more frequent and better quality services can be supported, with the benefits being passed onto passengers. Currently FDR is paid directly to bus operators according to how much fuel they use and refunds about 80% of the duty that operators pay on diesel[11]. LPG and CNG fuelled buses receive a 100% rebate, but EST has shown that the fuel costs of operating a diesel bus compared to a LPG bus is neutral once FDR is taken into account. The extra 20% rebate for switching to CNG or LPG has no impact on purchasing behaviour, as there is nothing to compensate bus operators for the higher capital and operating costs of a CNG or LPG bus. Hence the important point here is that the total costs of cleaner bus operation (including fuel, capital, maintenance and operating costs) need to fall to a similar level to that of diesel if it is to be adopted commercially by operators.

## International Experience with CNG Bus Fleets

The development of the CNG bus market has generally been driven by environmental requirements to improve urban air quality. For successful implementation, CNG buses have to perform effectively in the real world situation, but there are examples from around the world where this is not the case. A recent study by the International Association for Natural Gas Vehicles (IANVG)[12] found that only those operations that have committed to a large enough number of CNG buses to develop and support the necessary infrastructure, both in maintenance and refuelling, have had the greatest success. This requires long-term commitment and motivation by the operating organisation, combined with the opportunity to benefit from fuel cost savings and the need to meet strict environmental performance.

Some of the specific issues that were identified in this IANVG study were:

- CNG buses typically cost between 10 and 25% more than their diesel equivalents, and costs and reliability are of paramount importance to bus operators;
- The most successful fleets have had a third or more of their fleet converted to CNG. In addition, a fleet size of 50 or more buses gives significantly better results than smaller fleets, particularly if they are located at one depot;

[9] 'Quality Bus Partnerships Good Practice Guide', available via the TAS website www.tas-passtrans.co.uk
[10] Source: Independent market research carried out on behalf of EST, 2002.
[11] Also note the comments about the Bus Subsidy Review in section 1.
[12] 'Natural Gas Vehicle Transit Bus Fleets: The current international experience' IANGV, 2001.

- On-board fuel storage capacity will add about 17% to the vehicle weight;
- CNG buses have a range of about 400km, compared with 700km for diesels. The storage capacity involves a trade-off between the weight of the cylinders and the desired range and payload of the buses. Routes and distances travelled during a day need to be carefully considered to ensure there are no operational difficulties or added costs;
- The fuel efficiency of CNG is not as good as diesel, with a 10-15% penalty being observed;
- Maintenance costs may be more expensive, due to lower production volumes of parts;
- Reliability of CNG buses may not equal diesel. Difficulties with spark plugs, coils and ignition leads have been reported;
- Refuelling infrastructure costs are high, due to the compressors and storage volumes needed to ensure adequate capacity. Careful consideration of refuelling patterns and time to refuel, together with the sizing of compressor and dispensing units to match demand;
- Maintenance staff and drivers should be adequately trained;
- Before committing to CNG buses, it is essential that all regulatory issues have been resolved with central and local government agencies.

## European Experience with LPG Bus Fleets

LPG is used as a fuel for buses in most EU countries, and the current fleet numbers at least 1300 buses[13]. Experience with using LPG in buses has been researched and reported. This has shown the benefits in terms of reduced emissions of regulated pollutants and reduced $CO_2$ emissions. LPG buses also have reduced noise levels when compared with conventional diesel buses. However to get the best emissions performance from an LPG vehicle, a dedicated engine is required. Current bi-fuel and dedicated LPG engines have a performance similar to conventional fuels, and can give an extended engine life due to the cleaner fuel and lower engine stress. However, it should be noted that diesel vehicles can achieve significant mileage before the need for re-engining.

## European Experience with Electric Buses

There are several European designs of mini-buses and midi-buses which are powered by electric motors, using on-board batteries charged up by mains supply – mainly overnight. In the UK, these have included prototypes and trials in Bristol, Merseyside and Oxford. Experience has shown that the purchase prices are much greater than conventional buses, mainly due to the low production volumes and high costs of the battery equipment. Operating costs are relatively low, but the low energy densities of the lead-acid or nickel cadmium battery designs, together with short life-times and low charging efficiencies have tended to pose problems for bus operators. There remains much work to be done in developing an affordable rechargeable traction battery for all types of electric vehicles, and it is in the emerging area of hybrid electric vehicles that engineering and commercial interests are now focusing. Battery weight has an adverse effect on overall energy utilisation.

The purchase price of electric buses is much greater than that of diesel due to small batch production rather than serial volume production. Equipment derived from trolley buses is bulky and heavy and initial trials using industrial drives and motors have been successful.

Lead acid remains the preferred choice for electric buses with nickel metal hydrides as a possible alternative. The life and range of any battery pack can be extended if the battery is not deep discharged and currents in and out are limited. Options for achieving this have been discussed earlier in the text. Such developments together with larger production quantities will reduce the initial cost of the electric drive-line.

## European Experience with Hybrid Drive Systems

Several transport operators and manufacturers in Europe (and in the US) have developed and tested a range of hybrid-electric and diesel-electric vehicles in recent years. There are currently more than 100 hybrid or diesel-electric buses operating in almost 20 cities in Europe. Most of these activities have received backing from the EC THERMIE programme. A summary report using case studies from hybrid buses in five European cities was published by the EC in 1999[14], and the key findings are listed below:

- Hybrid technology is still at an early stage, and constraints of availability, reliability and cost need to be overcome before commercial production can be started;
- There are no common standards for comparable information about fuel consumption and emissions, and satisfactory testing procedures are still needed. Recommendations for test procedures are however being developed by the LCVP bus working group;

[13] 'LPG: a professional alternative motor fuel for the next 20 years', European LPG Association, Brussels, 2002.
[14] 'Urban Buses with Hybrid Drive Systems', European Commission and UITP, Brussels, 1999.

- Operating experiences showed that diesel-electric traction alone does not necessarily provide for lower energy consumption and emissions. The main advantages of hybrid-electric traction such as energy recuperation and higher efficiency of power transmission are counter balanced by weight penalties on the vehicle and sub-optimal power management;
- However, local demands for zero-emissions operation in city centres can be met, very low noise levels are generated in electric operating modes, and an enhanced image of the bus can be achieved;
- Hybrid buses could be a platform for future developments such as fuel cell vehicles.

## Current UK Clean Fuel Bus Fleets

In the UK, there have been several projects involving alternative fuels in buses. These have included LPG, CNG, biofuels and electric vehicles. However, experiences in the real-world situation have not been totally successful and it is only those operations that have committed to a large enough number of CNG buses to develop and support the necessary infrastructure, both in maintenance and refuelling, that have had the greatest benefits. Table 8 lists brief details of some recent projects involving alternative fuels for buses in the UK.

*Table 8:* **UK Examples of Cleaner Fuels in Buses**[15]

| Fuel Type | Location | Vehicles | Project | Equipment | Key findings |
|---|---|---|---|---|---|
| **CNG** | LB Camden | 3 minibuses Community Transport fleet | ASTI accessible Minibus project 1995-1998 | Iveco-Ford van conversions with dedicated Iveco gas engine | Technically successful, high capital costs |
| **CNG** | LB Merton | 19 dedicated CNG minibuses and coaches | CNG local authority vehicle fleet Current | Iveco Daily | High capital costs, weight penalty of on-board fuel storage. Driver training and awareness needed |
| **CNG** | Southampton | 6 converted and 10 dedicated CNG buses | Entrance project Hampshire County Current | Dennis Dart midi bus | High fuel use, high capital cost, good public response |
| **CNG** | Birmingham | 14 CNG buses on commercial service route | Travel West Midlands CNG demonstration Current | Volvo bus with dedicated lean-burn engine | High fuel use, high capital costs, some technical and maintenance problems |
| **CNG** | Merseyside | 4 CNG buses on Park and Ride route in Southport | JUPITER-2 project Merseytravel. Current | Dennis bus with dedicated gas engine | High capital and fuel costs |
| **CNG** | Northampton | 6 dedicated CNG buses | CNG bus fleet Current | Volvo bus with dedicated lean burn engine | N/A |
| **LPG** | Cheshire CC | 4 dedicated LPG buses for Park and Ride route in Chester | LPG demonstration 1998-2000 | DAF Bus International | Technically successful, but high capital costs |
| **LPG** | British Airports Authority | 17 LPG single deck buses at Gatwick Airport | LPG bus fleet | DAF Bus International | Operating since 2000 |
| **Battery-electric** | LB Camden | 3 minibuses for Community Transport fleet | ASTI Accessible Minibus project 1995-1998 | Iveco-Ford van conversions, lead-acid batteries and Wavedriver controller | Commercial case for battery electric minibuses was weak |
| **Battery-electric** | Merseyside | 6 minibuses for Hamilton Quarter in Birkenhead | JUPITER-2 project, Merseytravel Current | Tecnobus electric minibus | High capital cost, operator training and awareness needed |

## Case Studies of clean fuel bus operation in the UK

Six case studies are presented below of cleaner fuel bus fleet operations in the UK. These are the most recent data that are available on these operations. The case studies are:

- Dennis Dart CNG buses operated in Southport;
- Tecnobus Gulliver electric buses operated in Merseyside;
- Wrightbus electric hybrid bus operated in Bristol;
- Volvo dedicated CNG buses operated in the West Midlands;
- Mercedes diesel-electric hybrid bus operated in Portsmouth;
- Dennis Dart CNG buses operated in Southampton.

[15] Information sources: 'Report of the Alternative Fuels Group of the Cleaner Vehicles Task Force', DTI , London, March 2000; European Commission THERMIE programme, 1999; International Association of Natural Gas Vehicles, 2002.

# Arriva North West and Wales – Dennis Dart CNG Vehicles

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## Specification:

- 11.3m Dennis Super Pointer Dart (SPD) chassis with Plaxton Bodies, 8.3 tonnes
- 60 passenger capacity (40 seated, of which 24 plus a wheelchair are in the low floor section)
- Kerbside kneeling facility and ramp (entrance step 325mm, lowers to 250mm)
- Cummins "B Series" B200G natural gas engine, 145kW
- 3 lightweight, roof-mounted, composite CNG tanks per bus, total capacity 882 litres @ 200 bar (161.7kg)
- Vehicle maximum range 350-400km with full tanks

## Introduction and Project Overview

The Arriva Group has participated in a number of trials designed to reduce pollution and/or save energy. In particular, Arriva NW&W presently operate both CNG and LPG buses and also a large number of vehicles fitted with continuously regenerating particulate traps. This case study focuses on the experience of operating 4 CNG buses on Park and Ride routes in Southport, to help encourage a modal shift from the use of cars in the town centre. These vehicles formed one aspect of the European JUPITER-2 project to reduce exhaust pollution and save energy and to demonstrate sustainable transport policies in the Merseytravel region. The buses run under the SMARTeco brand, (as do some small electric buses not operated by Arriva and some diesel buses with innovative exhaust after-treatment using ultra-low sulphur diesel). The JUPITER-2 project also incorporates various route enhancements, such as real-time information and new passenger infrastructure in addition to integrated traffic management and support measures.

The CNG buses started operating in February 1999. Where possible, their performance has been compared with buses using ULSD, of which Arriva NW&W has experience going back to 1995 (ULSD is now their standard fuel). Some 35% of journeys in the total project area were made by bus, 30% by car and 25% by walking. Comprehensive surveys showed that awareness of the SMARTeco measures that were implemented was high, especially of the CNG buses themselves. Public attitudes of bus user and non-user alike to the CNG bus fuel were positive.

All the various elements of the demonstration, including passenger information, new vehicles and transport management measures were welcomed. Patronage of all three SMARTeco services taken together increased by an average of 17% in the period between the before and after surveys. After the first 9 months operation, the CNG services showed a patronage increase of 5% over the figure from two years previously.

The perceived environmental impact of the CNG buses was about half that of cars and diesel buses. The operating performance of the CNG vehicles was however worse than that of the electric and clean diesel buses. The CNG vehicles showed poor reliability during the initial period of operation and although the majority of these problems were solved, reliability levels continued to be lower than would be expected for vehicles of their age. Additionally, there were some problems with the gas refuelling plant that were attributed by the bus operator to variations in fuel quality and water in the gas.

Overall emissions from the CNG buses were considerably lower than those observed in previous comparable European projects. CNG has specific benefits in terms of NOx and particulate emissions (PM) compared with diesel-powered vehicles. Overall emissions are a function of all the vehicles operating in the project areas and the degree to which a modal shift was achieved from cars to buses. The combined results for the SMARTeco projects showed PM reductions of 0% while $CO_2$, NOx and hydrocarbon (HC) emissions were each reduced by 3-5%. Total transport energy use in the project areas was reduced by 3%.

Fuel cost comparisons depend upon the effective level of duty in force at the time. During the course of the SMARTeco project, changes in the fuel duty structure were made in favour of CNG and LPG. Paradoxically, these changes made CNG less commercially attractive for bus use. In overall cost benefit terms, the SMARTeco project had a short payback time of around 2 years. However, the use of CNG buses would be commercially disadvantageous to an operator at present. JUPITER-2 demonstrated that integrated transport projects, consisting of investment in alternative fuels, innovative technologies and transport management measures could influence modal split in favour of public transport and bring environmental benefits from reduced emissions and noise.

## Infrastructure Requirements and Related Matters

Upgrading of the Park and Ride service in the coastal resort town of Southport (pop. 75,000), north of Liverpool, was the second of the JUPITER-2 schemes to be implemented.


### Compressed Natural Gas Buses

The existing Park and Ride buses, although only 5 years old, were not easy to access and could only accommodate 35 seated passengers in very cramped conditions. Four Compressed Natural Gas (CNG) buses were introduced on two Park and Ride services. The buses did not have oxidation catalysts or particulate filters. A high quality interior and exterior image was specified for the CNG buses and the bus stops on the SMARTeco routes to create a distinctive identity for the new service. Enhancements included new, larger, accessible, low-floor CNG buses, a new livery, new high quality passenger facilities at all the bus stops, real-time passenger information at bus stops and on the buses, transponders fitted to buses to activate traffic lights in their favour, and upgrading of the Park and Ride sites and facilities.

The buses are understood to be exempt from vehicle annual test requirements but could be presented separately to obtain Reduced Pollution Certificates (RPCs), thus qualifying for a lower rate of Vehicle Excise Duty (VED).

### Fuel Supply Installation

Mobil Oil installed the natural gas refuelling infrastructure at the Southport bus depot during the winter of 1998. The refuelling station was a 'fast-fill' site, where vehicles could be refuelled to a pressure of 200 bar via a dispenser. Natural gas is taken directly from the mains distribution system, although not from the existing gas supply to the site, and passes through a compressor. The plant was relatively small, capable of handling 80 cubic metres per hour. This is sufficient however for the four buses to receive fast, complete filling, in line with normal operating procedures (a slow-fill installation permitting overnight refuelling would have been cheaper, but the layout of the depot was not compatible with this approach).

After compression, the CNG is stored in three separate banks of gas tanks. The first set of gas tanks stores gas at approximately 140 bar and is used for bulk filling of empty vehicle tanks. The second bank of tanks stores gas at approximately 200 bar. This set is used if the pressure in the vehicle's gas tanks is greater than about 130 bar – either following initial filling of an empty vehicle from the first set of tanks or when a vehicle arrives for refuelling after a short duty cycle. The third set of tanks stores gas at approximately 250 bar and is used for final topping up of vehicles to 200 bar. This arrangement is designed to prevent the operator regularly having to attach the highest pressure tanks in the filling station to empty vehicles, although pressure regulation valves are in place to limit the flow of gas in such a situation. The process is completely sealed and no fuel is vented to the atmosphere. The system is designed to automatically shut off once the gas containers on the vehicle reach a pressure of 200 bar.

CNG refuelling is now a relatively mature technology considering the first UK plant was constructed some 16 years ago and the Southport installation has functioned well. The typical gas filling time for a Dennis SPD vehicle is 10 minutes. This is somewhat longer than that required for a diesel bus. The additional filling time could cause operational problems at congested bus garages with a large fleet of CNG vehicles, but is not a concern at Southport. The refuelling plant requires high-pressure filtration changes every 200 hours to ensure that dry gas is delivered to the vehicles. The moisture problem was probably due to the use of old Victorian mains – modern medium to high-pressure plastic mains are preferred to avoid water ingress.

**Health and Safety Implications**

Every three years the tanks must be removed from the buses, pressure tested and re-certified, fitted with replacement valves and re-installed on the bus before testing *in situ*. This costs over £3,000 per vehicle. The buses are checked in-house monthly for gas leaks and the pods are lifted quarterly by Arriva personnel. There can be no direct overhead heating near the maintenance pits due to the presence of the roof-mounted tanks on the buses. CNG is lighter than air and so will not accumulate in maintenance pits (unlike LPG), but use of CNG requires the buses to be parked outside at night.

**The Park and Ride Routes**

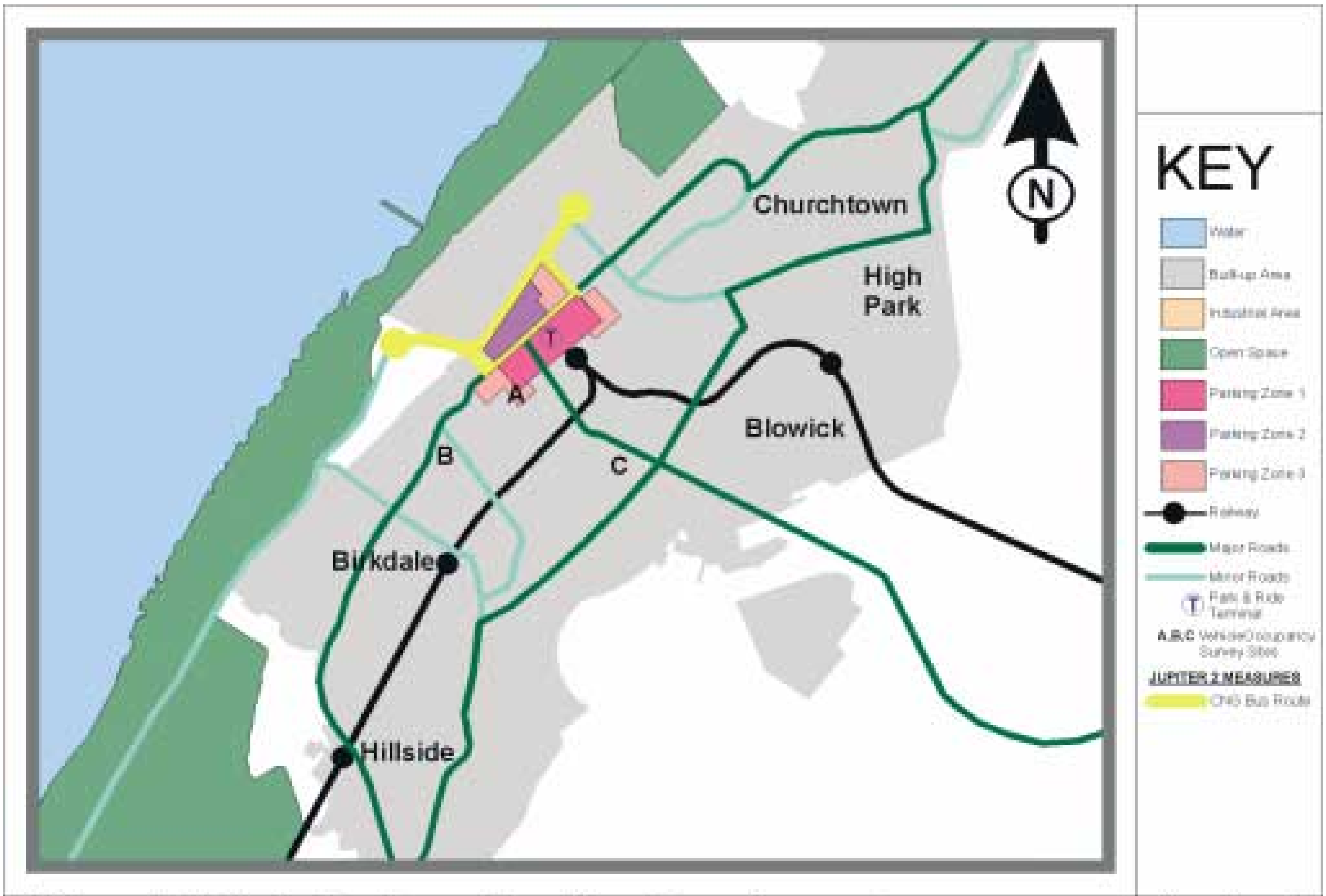
Two Park and Ride services are operated. The main route operates at 10 minute intervals during the week and during the summer (15 minutes on Sundays). The other runs at 15 and 20 minute intervals. These duty cycles, with relatively short routes and long waits, differ from most urban bus services.

**Public perception of the CNG service in Southport**

Of the service changes in Southport, the gas-powered buses had the greatest impact on Park and Ride users. Nearly two thirds of passengers surveyed were aware that they were travelling on a CNG-powered bus, and in another survey, a noticeably higher score was awarded to the comfort of bus category, following the upgrade to new, quieter CNG buses. In the 'after' surveys, passengers on the Park and Ride buses and people in the town centre were asked for their opinion of the upgraded service, with CNG buses having the greatest impact.

**Staff Training and Vehicle Maintenance**

Drivers, maintenance personnel and refuelling staff all required appropriate training which included the health and safety aspects associated with CNG. A special engine oil is used which is changed every three months compared with the normal six monthly interval between oil changes for a diesel bus.




The JUPITER-2 project in Southport.

## Vehicle Operation and Performance

The performance of the CNG buses was monitored for the Park and Ride service, and occasionally for other routes. In the early stages, about 25% of possible operating days for the four CNG buses was lost, mainly due to engine misfiring and related issues (one bus gave particular problems). Recent performance has improved, but reliability is still worse than conventional diesel vehicles.

Particularly during the early winter months there were some problems with the refuelling plant. Staff suspected that the CNG was spiked with propane to improve its combustion properties, but that this caused problems to the filters in the filling station. There were also early problems with water in the gas supply that caused icing of the delivery nozzle and affected 12V solenoid valves on the buses which often left only one or two tanks open, reducing the vehicle range.

The Gas Fuel Injection (GFI) engine pressure regulating valves typically fail, or leak, annually and replacement costs £1,000 per bus. Other gas leaks can cost some £300 each to repair by a specialist sub-contractor. Engine Management System (EMS) problems cost about £1,000 per bus annually for Cummins to diagnose and rectify. Available on-bus equipment associated with the use of CNG was run on a 12V bus electrical system, compared with the standard 24V system. This added to the complexity of the installation, but in practice did not affect reliability.

### Vehicle Energy Consumption, Emissions and Fuel Costs

Some fuel consumption data was collected for the CNG buses in service to allow comparison between their performance and that of the diesel vehicles. CNG vehicle performance averaged over the period 11/2/99 to 31/12/99 was

| | | |
|---|---|---|
| **Miles covered** | | 46,447 |
| **CNG supplied (kg)** | | 30,217 |
| **Fuel consumption (miles / kg)** | | 1.54 |
| **Energy consumption (MJ / km)** | | 20.74 |
| **Net fuel cost – CNG (pence / km)** | | 9.1* |
| **Range on a full gas tank** | km<br>miles | 401<br>249 |

*7.1p/km for a comparable diesel bus

The comparative fuel costs of operating diesel and CNG vehicles are highly dependent upon the level of duty applied to the respective fuels and the level of fuel duty rebate available to bus operators at any particular time. A study by the vehicle operator in 1999 suggested that the net fuel costs to the bus company were 22.3 pence/kg for CNG and 24.93 pence/litre for diesel at that time. This equates to a fuel cost of 9.1 pence per kilometre for CNG (as shown in the above table). The fuel cost of a comparable diesel vehicle was then approximately 7.1 pence per kilometre.

The life cycle energy use of the CNG buses, which appears to be worse than that of ULSD combined with particulate traps, is summarised below.

| | CNG |
|---|---|
| **Energy use per available seat-km (MJ/skm)** | 0.55 |
| **Energy use per used seat-km (MJ/skm)** | 1.54 |
| **Net fuel cost per available seat-km (p/skm)** | 0.23 |
| **Net fuel cost per used seat-km (p/skm)** | 0.64 |

Emission testing at Millbrook gave the following results:

| Emissions (g/km) | $CO_2$ | HC | CO | NOx | PM |
|---|---|---|---|---|---|
| **Park and Ride cycle** | 1106.1 | 10.441 | 5.659 | 3.710 | 0.052 |
| **London Transport cycle** | 1151.4 | 11.907 | 6.262 | 4.644 | 0.055 |

In comparison to results for CNG vehicles used in the previous round of THERMIE transport projects (1993-1996), these results show significant improvements in emissions performance. Life-cycle emissions per available and per occupied seat on the CNG buses were also calculated and compared with other energy sources. CNG performed well for NOx and particulates, but less well for CO and hydrocarbons. In addition, ULSD and CRT™ technology performed well for CO, particulates and hydrocarbons, but allowed the highest NOx emissions of the fuels used.

## Next Steps

The CNG buses contributed significantly to the success of the JUPITER-2 project and continue to operate successfully. Due to the various route enhancements included within the overall project, it is difficult to assess the specific contribution of quieter CNG buses to the observed modal shift from cars, but the pollution benefits are clear.

Present Government policies and bus operating subsidy arrangements affect the relative benefits of alternative fuels. At present there is little commercial incentive for bus operators to use CNG. Access to Clear Zones and AQMAs is likely to be achievable with ULSD and suitable engines.

Some of the valves that have given trouble on early CNG buses will be made more reliable by development for truck use and mainland European demand for bus applications. However, it is likely that diesel buses will continue to be more reliable than CNG vehicles and inherently cheaper, although the cost differentials will decrease.

# Merseytravel – Tecnobus Gulliver Electric Vehicle

**Contact information**

Merseytravel

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## Specification:

- Model: Tecnobus Gulliver U500EUK;
- Wide front entrance (1,100mm) with side handrails;
- Kerbside kneeling through air suspension which reduces the entrance step height from the standard 330mm to 270mm;
- Air suspension system guaranteeing passengers a smooth ride;
- Powered boarding ramp to provide wheelchair access which is 900mm wide;
- Battery electric power with computer controlled 'chopper' to ensure a smooth, quiet and vibration free journey;
- Battery electric power which provides zero emissions at street level;
- Fitted with on-board electronic information displays, indicating approaching stops.

## Introduction

The SMARTeco branded Gulliver buses (resulting from Merseytravel's participation in the JUPITER-2 European project) were operated in the Hamilton Square region of Birkenhead and were the first of three schemes to be implemented under the same project (the other two schemes featured CNG buses as part of a P&R scheme, and the upgrading of four bus services to run on clean diesel using innovative exhaust after-treatment).

The Hamilton Quarter scheme using electric buses complemented the Hamilton Quarter urban regeneration project which had been underway since April 1995 following Government approval of an ambitious regeneration programme put together by a partnership of public, private and voluntary organisations. The overall regeneration project was charged with delivering, by the year 2002, a package of measures for the economic, environmental and social regeneration of the historic core of Birkenhead Town Centre and Hamilton Square.

The SMARTeco scheme represented part of a comprehensive strategy of environmental improvements in the Hamilton Quarter. A new traffic system reduced the amount of through traffic in Hamilton Square, which included improved accessibility for buses and cyclists and made the area safer and more pleasant for pedestrians. The main features were:

Two-way traffic in Argyle Street between Hamilton Square and Hinson Street;

- A southbound bus lane in Hamilton Square;
- Pedestrianised space in front of Hamilton Square Station and the Town Hall;
- More short-stay disc parking around the Square;
- Improved bus facilities including new bus stops in Bridge Street;
- A new excursion coach pick-up and setting-down stop in front of Shore Road Pumping Station;
- A taxi rank in Hamilton Street by Hamilton Square Station.


The E1 electric bus service was introduced to augment these traffic changes by providing a realistic alternative to the private car in the Hamilton Square area. This ensured that the growing dominance of private traffic did not undermine the continuing efforts to provide a pleasant and healthy environment for residents and local businesses. Operating between Birkenhead Shopping Centre and the Hamilton Quarter, the scheme featured buses running every 7 minutes during the day with lower frequencies in the evening. The one-way service loop also served the newly opened Conway Park Station, Hamilton Square Station, Woodside Ferry and the new Birkenhead Bus Station which together provide links to the rest of the Wirral and Liverpool City Centre.

To encourage use of the service Merseytravel, in partnership with the Hamilton Quarter, implemented a full package of measures which combined to create the following level of service:

- The new electric minibuses were low floor and fully accessible with a powered boarding ramp and wheelchair bay;
- New high quality passenger facilities at all bus stops;
- Real-time passenger information at most bus shelters;
- Vehicle activated barriers by way of vehicle mounted transponders to permit access to pedestrianised areas;
- Innovative methods of recharging batteries to demonstrate using contact-less inductive charging;
- Bus stops and bus-only links surfaced with a green material to emphasise that certain areas of road space were intended for public transport and not for other vehicles.

## Infrastructure requirements and vehicle purchase/adaptation

Merseytravel placed a contract for 6 Gulliver electric minibuses, manufactured by Tecnobus of Italy, in March 1998. The total capital cost of the 6 vehicles and associated battery and charging equipment was £539,032. This followed a detailed evaluation of four types of electric vehicle. The final choice of vehicle was based on capital cost of both the vehicle and recharging infrastructure. The choice of vehicle was strongly influenced by the proposed route and frequency as well as the need for well-proven and reliable product and battery technology.

The non-standard specification of the vehicle compared with vehicles already operated by Merseyside bus operators meant that Merseytravel preferred to purchase the vehicles themselves and loan them to the operator who submitted the successful bid to operate them. In the event, the contract was awarded to First Group plc subsidiary, First Crosville Limited, for a period of 5 years commencing on 1 October 1998, at a total annual operating cost of £206,000.

UK practice of driving on the left raised some design issues which were tackled jointly by Merseytravel and the City of Bristol who had deployed two Gulliver electric minibuses as part of the European CENTAUR project. Moreover, the vehicles had to be designed and certified as public service vehicles with a minimum of nine seats (one more than the standard production version of the Gulliver minibus) using the provisions for minibuses in Schedule 6 of the Construction and Use Regulations. To comply with these regulations the following modifications to the vehicles were carried out:

- An off-side emergency door at least 1,200mm high and 525mm wide;
- An additional seat to bring the number of seats up to 9;
- A means of opening the doors on the outside of the vehicle, adjacent to those doors;
- A speedometer capable of reading miles per hour.

With these changes the vehicle was certified for seated passengers alone, with a review to allow standing passengers to be considered at a later date. The authorisation of a vehicle to allow standing passengers in a vehicle with less than 13 seats would require a change to the Carrying Capacity Regulations together with a notifiable alteration application to the UK Vehicle Inspectorate.

## Vehicle reliability and maintenance

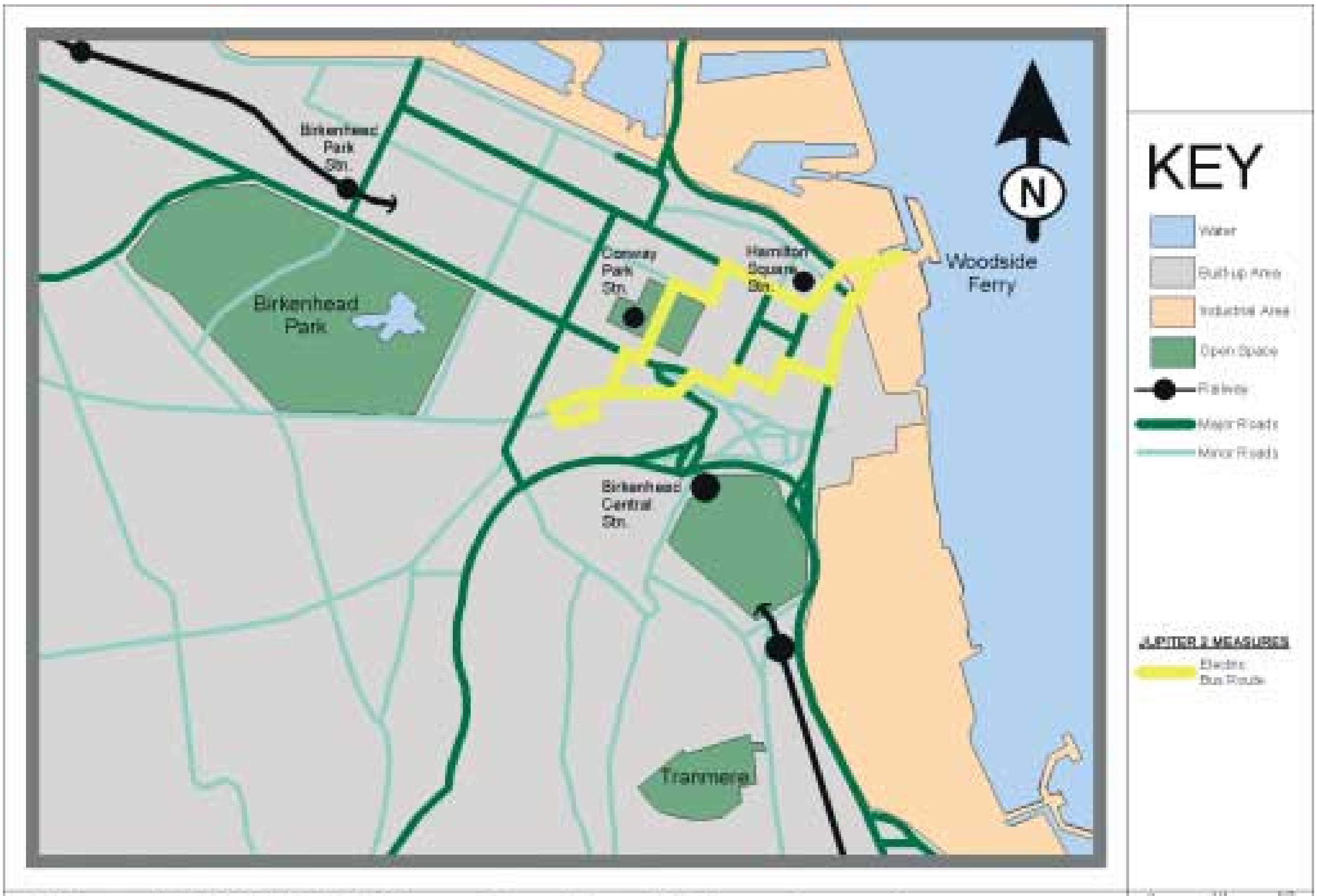
The operator of the E1 service, First Crosville, monitored the reliability of the electric vehicles in terms of the lost miles that occurred as a result of vehicle breakdowns (ie. miles operated compared with scheduled mileage). In the majority of cases this merely relates to the time taken between the vehicle fault being reported and the spare vehicle being placed into service.

In total, only 319 operating miles were lost due to breakdowns in the period between 19/12/98 and 23/10/99. This compares with a total operating mileage in this period of 96,536. Therefore only 0.33% of the scheduled mileage was undelivered, which emphasises the reliability of the vehicles. Furthermore, problems with the battery technology were responsible for only 119 of these lost miles, with the remainder being due to problems with standard features such as body panels, brakes, cabin heaters, doors, destination blinds, windscreen wipers and the access ramp.

The contract for the E1 service specified that a spare vehicle should be available due to the fear of unreliability in such a revolutionary project. However, the reliability of the vehicles proved to be so good that Merseytravel investigated the possibility of putting the spare vehicle into service during peak periods to reduce the problems of limited vehicle capacity and high demand. The special maintenance was undertaken by Tecnobus until March 2000 when it transferred to Crosville at an annual cost of £72,000. The effects of the transfer are currently being evaluated.

## Vehicle operation and performance

The vehicle was expected to be capable of operating up to 17 hours per day. Hence the flexibility of the Gulliver bus, which allowed batteries to be charged off the bus with battery changes taking less than 5 minutes to complete, was an important consideration. Battery packs take 7 to 8 hours to charge fully, but with up to 12 hours available to charge batteries overnight this did not pose a problem. The schedule dictated that the longest duty on a single charge was 6 hours covering 70 to 80 kilometres. Depending on local operating conditions the vehicle has a range of 100km. The original batteries are currently being replaced at a cost of £40,800 for 12 sets.




The JUPITER-2 project in Birkenhead.

Source: Merseytravel

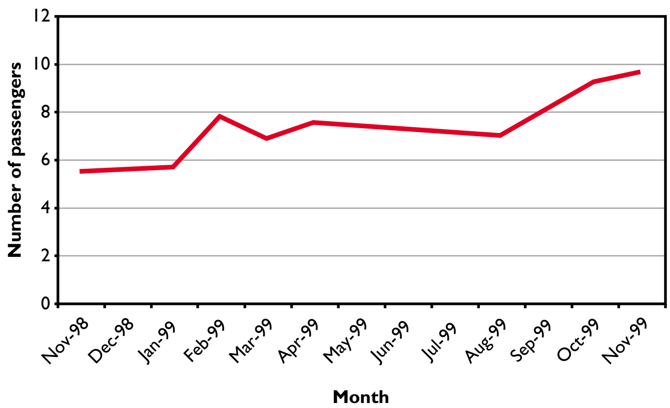
Driving staff and management of the bus company were all new to working with electric public transport vehicles and had the following opinions about service E1:

- The vehicle performance was well suited to a town centre route such as the E1;
- Some drivers questioned if there is a need for this service at night when virtually no-one uses it;
- There was also a question of whether reversing the direction of operation would actually be better to help interchange between transport modes in Birkenhead;
- Driving such a short route for a full shift is very repetitive and boring and although the scheduling avoided drivers being on the E1 service for more than 3 hours at a time, when a longer shift had been unavoidable the drivers viewed it with dread;
- The issue of how to collect fares was one that the management were keen to resolve.

The overall perception was that the minor initial problems with the E1 service and the vehicles had already been solved and that the issue of children mucking about with the evening services was the most important issue to be resolved.

## Demand

Surveys were conducted throughout the course of its first year of operation to keep track of the level of use of the new bus service. The results of these surveys, combined with a detailed analysis in April 1999 showed an upward trend from 5.5 passengers per circuit in November 1998 to 9.6 in the same month of 1999 (see below figure).




Surveys were conducted to count how many people were using the electric bus throughout the day. The results showed that there was very little use of the service before 10am or in the evening with patronage peaking in early afternoon. The peak patronage over the period occurred between noon and 1pm. Although the data at this time of the day seemed to indicate that the bus was well above its nine seat capacity, it is important to note that the above figure presents the total number of passengers using the bus on each whole circuit, rather than number of people on the bus at one time. However, there can be little further increase from this level of patronage due to the nine-seat capacity of the bus.

## Electricity Consumption

Detailed analysis of the performance of the electric vehicles was carried out on behalf of Merseytravel by EA Technology. The results of this study showed that the average energy consumption of the vehicles, measured as the electricity input to the battery charging units at the bus depot divided by the total distance travelled by the vehicles was 0.79kWh/km or 2.84MJ/km. Using data for the average efficiency of electricity generation in the UK this equated to a life-cycle energy consumption of 7.96MJ/km.

For the majority of the study period the bus operator was recharging the used batteries as soon as they were removed from the vehicles. This meant that the vast majority of the charging was done using peak-rate electricity. Towards the end of the study period a timer was installed which meant that the batteries removed from the vehicles at the end of the working day could be recharged overnight using cheaper, off-peak electricity. Even though the details of the electricity supply contract between Manweb and First Crosville are confidential, an indication of the fuel costs is shown in the below table which uses average UK electricity supply costs to small industrial users in the calculations.

| Charging Regime | Cost (pence per km) |
|---|---|
| **All batteries charged during peak rate.** | 4.5 |
| **Overnight charging of one set of batteries per bus at off-peak rate.** | 2.9 |

The fuel costs of the electric vehicles were low compared to standard diesel vehicles, although the latter are obviously much bigger and so have a larger passenger capacity. The ability to recharge overnight cuts overall electricity costs by a further 36%, which would lead to a saving of approximately £2,200 per year.

To enable comparison between the disparate vehicle types used in the three SMARTeco schemes, energy use and fuel cost were expressed in terms of life-cycle energy use per available seat. The results are shown in the table below.

| | Electricity | CNG |
|---|---|---|
| **Energy use per available seat-km (MJ/skm)** | 0.89 | 0.55 |
| **Energy use per used seat-km (MJ/skm)** | 1.59 | 1.54 |
| **Net fuel cost per available seat-km (p/skm)** | 0.32 | 0.23 |
| **Net fuel cost per used seat-km (p/skm)** | 0.58 | 0.64 |

The results showed that in terms of energy use, the combination of ultra-low sulphur diesel and CRT™ technology appeared to give the best results. In terms of operating costs, the CNG and clean diesel options gave the best results, although this result is somewhat skewed by their greater capacity. Actual efficiency in terms of operating cost would depend both on the level of patronage achieved and additional operating costs such as maintenance.

## Emissions Performance

Emissions at the point of use from the electric vehicles are clearly zero, which is their major attraction. However, electricity production methods currently result in emissions at the point of generation. The below table illustrates typical life-cycle emissions values for the electric buses using average emissions data for the generation of electricity in the UK.

| CO (g/km) | $CO_2$ (kg/km) | NOx (g/km) | Particulates (g/km) | THC (g/km) |
|---|---|---|---|---|
| 0.19 | 0.394 | 1.0 | 0.06 | 0.72 |

To enable comparison again between the disparate vehicle types used in the three SMARTeco schemes, emissions results were expressed in terms of life-cycle emissions per available and per occupied seat on the three different services. The results are shown below.

| | Electricity | CNG |
|---|---|---|
| **CO per available seat-km (MJ/skm)** | 0.02 | 0.14 |
| **CO per used seat-km (MJ/skm)** | 0.04 | 0.40 |
| **NOx per available seat-km (p/skm)** | 0.11 | 0.10 |
| **NOx per used seat-km (p/skm)** | 0.20 | 0.28 |
| **Particulates per available seat-km (MJ/skm)** | 0.007 | 0.002 |
| **Particulates per used seat-km (MJ/skm)** | 0.013 | 0.005 |
| **Hydrocarbons per available seat-km (p/skm)** | 0.08 | 0.39 |
| **Hydrocarbons per used seat-km (p/skm)** | 0.14 | 1.09 |

The data show that in terms of life-cycle emissions and the vehicle capacity to transport people:

- Electricity performed extremely well for all pollutants, although less well than the other options for particulates;
- CNG performed well for NOx and particulates, but less well for CO and hydrocarbons;
- Ultra-low sulphur diesel and CRT™ technology performed well for CO particulates and hydrocarbons, but allowed the highest NOx emissions of the fuels used.

It should be remembered that the data referred to life-cycle emissions and that the electricity emissions all resulted from generation. Unlike the other vehicles, there were no emissions from the electric buses at the point of use.

## Next steps

It would be expected that the introduction of fares on the service would have an impact on patronage. However, until their introduction, a solution must be found to prevent the electric buses running at capacity and therefore having to refuse entrance to passengers.

A revision of the timetable to incorporate a shorter running time and the introduction of the spare bus into service would mean that the headway could be reduced from every 7-8 minutes to every five minutes and would increase the potential number of passengers carried.

In the after survey at the ferry terminal, 62% of respondents were travelling from there into Birkenhead, but only 5% of this group were intending to make their trip by electric bus. Therefore, the potential exists for the electric bus to increase its share of the modal split for such journeys.

## Conclusions

The following conclusions were drawn:

- Environmental analysis has confirmed the significant impact that electric vehicle technology can have on energy use and emissions both within the urban area and over the whole life-cycle. The implementation of a single service such as the E1 can have an impact in the limited area that it serves. However, a wider network of such services would be needed in order to have a significant impact in Birkenhead as a whole;
- A significant reduction in traffic has been recorded in Hamilton Square where through traffic is now prohibited on two sides;
- There has been a resultant reduction in noise in all parts of the square;
- Patronage of the E1 electric bus has grown steadily since its introduction with late morning/early afternoon the period of highest use;
- Public attitude towards the E1 electric bus service is positive and in general the people surveyed believe it to be a good idea with little environmental impact compared to cars and diesel buses.

Overall, the electric bus service has been implemented successfully with no major operational problems. It has proved extremely reliable in operation and popular with its users. The problem of vehicle capacity remains an issue, as the vehicle contains just 9 seats and current UK minibus regulations preclude the transport of standing passengers, even though the vehicle has been designed and used in Italy for some time with up to 14 standees.

# First Group – Wrightbus Electric Hybrid Vehicle

**Contact information**


| | | |
|---|---|---|
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| Philip Panel | (Depot Engineering Manager, First Group) | |
| Maurice Perl | (Director, The Wright Group) | Tel. 028 2564 1212 |


## Specification:

- 120kW electric drive system;
- 30kW micro turbine (hot gases from combustion provide rotational power which is converted to an electrical output);
- 32kW hours battery;
- Suited to stop/start conditions;
- Range of 150-200 miles;
- Acceleration of 0-10 in 5 seconds, 0-30 in 18 seconds;
- Top speed of 40-45mph;
- LSD, CNG or LPG fuel options;
- Gross vehicle weight of 12.5 tonnes;
- Passenger capacity: 31 seated, 20 standees;
- Fully DDA compliant.

## Introduction

For a one week period in February 2003, the Wrightbus was trailed by the operator First Group from their Laurence Hill depot in Bristol. The aim was to gather initial findings on the real-life application of the bus both in terms of technical performance and service provision criteria. The trial was co-funded by First and Bristol City Council as part of VIVALDI, a European Commission supported project aimed at promoting sustainable transport in urban areas. The entire cost of the trial (including vehicle supply, travel, the exclusive use of the Wrightbus mechanic and subsistence) was around £5,500. The bus has also been trailed for short periods in Leeds and London where it received enthusiastic support.

## Infrastructure requirements

The depot had to install a 3-phase power supply to enable charging and equalising of the vehicle battery system.
A computer is used to monitor and correct the power level variance (brought about by standard vehicle operation) in the vehicle's 56 batteries. Battery levels can vary between 12-14.5V after operation, so it is important they are periodically equalised to the optimum 13.5-14V to ensure battery life and vehicle range. While at Bristol, the vehicle was left to equalise over night, but in reality the operation only takes 2-3 hours. This is obviously an added bonus when considering the use of these vehicles in the day and on a shift system. The cost of the supply installation was £676 (excl. VAT) and would be required for each additional vehicle if not following a rotational shift system whereby buses use the same point. An outside contractor was brought in to do the job.

If First Group were to adopt the Wrightbus in future, they would probably utilise their current electricians at the depot and 'tweak' their knowledge to suit the demands of the Wrightbus equipment. Incidentally, no additional infrastructure was required to accommodate the low-sulphur diesel element of the vehicle.

## Staff training and vehicle maintenance

Some staff training was needed because the smooth speed take up and slow down is different from conventional bus operation and changing driver throttle habit aids performance sustainability. Other controls are the same as for a comparable conventional bus, except for the 'start-up' procedure where button operation is required to activate the turbine.
The starting of the vehicle (ready to run on electric power initially) is then carried out automatically with the turbine cutting in as demanded to ensure sufficient power is maintained.

First Group had the support of a dedicated Wrightbus mechanic on-site at the depot. This resource proved invaluable to ensure that the professional support was available in keeping the vehicle on the road and running at optimum performance. If the vehicle were to enter full-time operation, the manufacturer offers lifetime back-up from their parts and service division.

Health and safety regulations pertinent to the depot and operating the vehicle on-site were sent to all external contractors prior to the trial start, thus ensuring all staff were aware of the issues involved when incorporating the Wrightbus into the larger schedule of service operation. This culminated in a final on-site briefing session for all staff involved.

## Vehicle operation and performance

The vehicle experienced real-world operation when it was assigned to Routes 8 and 9, a busy journey connecting the main train station to popular parts of Bristol via the city centre. The service ran on time and the overall impression given by passengers and the driver was very positive.

The vehicle has a surprising range and ability to keep on running due to the highly efficient micro-turbine that helps to keep the batteries charged whilst moving around. In contrast to other conventionally fuelled vehicles, the Wrightbus is ideally suited to stop/start movement in the city because it allows the turbine to regenerate the power in the batteries to great effect (plus regenerative braking). This bus is not designed to run for extended journeys at a consistent speed (even though a top speed of 45mph was reached on the city's M32). Park & Ride application would need individual evaluation depending on route length, traffic conditions and stop-over time (power recovery time).

The vehicle (like other electric drives) was expected to have some trouble with gradients, but after having been put through some of the toughest in Bristol the vehicle seemed to handle it quite with ease, in fact no noticeable difference was made from that of a conventional diesel and in some cases an improved performance was noted against conventional diesel buses. A slight reduction in ability to accelerate was noticed, but this does not necessarily represent an adversity for urban operation. Deceleration was found to be the same as for a conventional vehicle.

Air quality emissions were ultra low with NOx, CO and noise levels particularly impressive. Millbrook tests show the hybrid bus NOx at 0.48g/km (Euro IV for 2005 = 3.50) and CO at 0.24g/km (Euro IV = 4.00). Fuel consumption and $CO_2$ test results were however not as promising as expected, and further development and testing work is planned in the near future, with the expectation that issues can be resolved. Noise levels of around 65dB constant were measured in London.

One example of possible concern, especially in an urban operational context, is simply the lack of sound produced from running the electric hybrid vehicle. Although noise pollution is greatly reduced, it can work to the extent where people may be put at risk in today's climate because they think if they do not hear anything like a diesel engine, there must be no bus coming. As a result, special care is sometimes required on behalf of the driver when driving in close proximity to people (eg. in the city centre) in order to avoid collisions with pedestrians. As is standard practice with all First Group vehicles, headlights are kept on at all times as an extra safeguard. The manufacturer is investigating whether additional noise recognition on approach is needed.

The operator commonly looks for a 12-year structural lifespan for its mini/midi vehicles and 15 years for a single-decker vehicle. The structural lifespan of the Wright hybrid bus will be similar to conventional buses since only the power train elements in the vehicle are different. Power train life expectations are still unknown but with only one moving part the turbine is expected to offer an approximate 10-year life and low parts replacement costs. Similarly the electric drive is expected to be a low maintenance item outliving normal bus life. The unknowns arise over battery life and this will depend in part on future battery selection and development. Current life expectation from the battery manufacturer is around 3/4 years that indicates 2 replacements in its operational life, roughly equivalent to replacement costs for a conventional ICE and transmission. These issues will only be fully gauged through further trailing and operational work.

## Next steps

The Wrightbus trial highlighted the capability between manufacturer, operator and local authority to actively work towards trying new technology and developing what is certainly a transport option of great potential. First Group hope to bring the bus back for a 4/5 week trial in the near future, thus providing a more extensive opportunity to assess its viability within the company's existing operations.

# Travel West Midlands – Volvo Dedicated CNG Vehicle

**Contact information**


| | | |
|---|---|---|
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## Specification:

- Volvo GH10A 245 lean-burn CNG engine, and Volvo B10L chassis;
- Volvo Saffle body built under licence by W Alexander, Belfast;
- Single-deck, low-floor;
- Top speed of approximately 50mph;
- 245bhp engine driving a 5-speed ZF automatic gearbox with integral retarder;
- CNG is stored at a pressure of up to 200 bar in 5 roof mounted cylinders each carrying about 220 litres and of composite construction;
- Range of 200-250 miles;
- Acceleration similar to a single-deck DERV equivalent;
- Gross vehicle weight of 17 tonnes (could in theory be increased to current legal limit of 18 tonnes by replating the vehicle, and therefore increasing 'standing' passenger capacity);
- Passenger capacity: 41 seated, 26 standees (1 passenger less than DERV equivalent).

## Introduction

Since 1997, TWM have been running 14 dedicated CNG powered buses, firstly along a route connecting two adjacent urban areas, and then dispersal to a variety of other destinations. The buses are a commercial enterprise serving real fare-paying customers. They are kept at TWM's Walsall depot alongside conventionally fuelled buses.

The original purchase cost was about £145,000 per vehicle. The total cost for the original project was about £2,310,000 (mainly for fleet purchase). TWM funded 74%, British Gas 15% (for infrastructure), Volvo Bus Ltd 6% (also discounting the total fleet cost) and the Energy Saving Trust 5% (ie. funded £10k of the £40k premium for each CNG bus).

## Infrastructure requirements

The infrastructure and equipment originally cost about £300,000, but this was met by British Gas as part of a contract to supply gas for the next 10 years.

The CNG vehicles are returned to the depot every evening in order to refuel ready for the next day. The system used is a regular 'fast fill' one where two buses can be refuelled simultaneously (duration is about 15 minutes). Gas is stored under pressure in banks of cylinders and is drawn off accordingly – the compressor cuts in as the pressure drops but the point is that there is storage of gas under pressure ready to use as a result of its activation during the day. Some of the buses do refuel during the day as well. Staff involved in the refuelling process were given a 1-hour briefing to ensure they followed the appropriate procedures and were knowledgeable about safety. The physical space requirements for the refuelling infrastructure equate to the same amount of space that would be required by about 5-6 buses.

The existing infrastructure is sometimes over-utilised and requires additional capacity in order to accommodate all 14 buses. Whilst British Gas maintain that only limited additional capacity would be required to remedy this, TWM would need to be convinced of the need not to have the infrastructure doubled in reality. Ideally, as in some European countries, it would be most beneficial to have individual docking bays for each vehicle, therefore providing maximum capacity for vehicle refuelling and much increased flexibility. At present, TWM are restricted by land-use constraints and the vehicle cost/benefit achievable by taking such an action. The station is, however, usually capable of refuelling other vehicles from outside the depot when needed.

## Staff training and vehicle maintenance

All maintenance specifically to do with the CNG engine is contracted out to Volvo. The service provided by Volvo has come under heavy criticism for a variety of reasons. For example, the technological components involved in the engine's physical make-up have been noted for various faults and breakages, including a fundamental valve that regulates the pressure level of gas as it leaves the cylinders at 200 bar and is mixed with air at about 10 bar before entering the combustion chamber – the valve proved to be very unreliable. The lean burn engine was also susceptible to gas quality inconsistency (natural gas is supplied in varying levels of quality according to the field being tapped into at the time – calorific value however is ensured constant from the supplier).

The re-furbishing of vehicles in a number of ways (including the remedy of the above valve problem and other issues mainly in the area of engine modification) has finally resulted in better performance from the vehicles. At present, around half the vehicles in the fleet have completed this upgrade process. The associated costs are around £25,000 per vehicle. In the event of breakdown, Volvo has to recover the vehicle as part of their maintenance contract. Vehicles can be out of action for a maximum of 2-3 weeks, depending on the problem.

Parts replacement for the vehicles can be expensive when compared to diesel counterparts. This is often because of the inferior supply network that exists when compared to diesel which has been built up extensively over time. Specialist parts have to be ordered and sent over from Sweden, resulting in delayed vehicle maintenance.

On average, operators can expect to have their vehicles under maintenance for a total of 300 hours (for the first 5 years) with a conventional diesel vehicle. TWM however have experienced this value to be about 800 hours for their CNG buses. This is where the bulk of additional expenditure is hence realised.

The cost for the maintenance contract with Volvo is about £2,000 per vehicle per month for the next 5 years. This represents an increase on those rates charged during the first 5 years, mainly due to the high level of maintenance work that was incurred during this initial phase. Volvo believe that this could be significantly reduced though if requirements for testing the composite construction gas storage cylinders (for certification purposes) were removed. Traditionally, a steel cylinder has to be re-certified every few years (typically 5) via a pressure test. Composites do not suffer from fatigue however, so a pressure test is arguably meaningless and very expensive due to the gas system having to be dismantled and the residual gas vented to the atmosphere. Tests carried out by TWM every 3 years could therefore be making the respective maintenance contract more expensive than is necessary.

Drivers were not given any special training in order to operate the CNG vehicles, simply the standard training required to operate most vehicles. The vehicles were originally operated by drivers already familiar with the respective journey involved (Route 529). This assisted in the smoother operation of these buses because route knowledge enabled the drivers to speak easier about the new buses to customers and allowed them to feel more confident in handling the vehicle (and in the case of breakdown also).

Customer perception of the vehicles was initially mixed, with concerns about safety of the vehicle. Drivers were however informed of many of the technical aspects of how the vehicles were run and this enabled them to reassure and comfort any concerns held by passengers. Passengers did comment on the quietness and increased space of the vehicle – with no fuel tank at floor level, there was more space at the front end. A much better overall perception is now held by most passengers.

Another issue encountered was that of heat – the engine ran much hotter than the diesel equivalent. The heat meant that the floor at the back of the bus used to get warm and the air in the saloon used to get uncomfortably hot – with no opening windows in the area, a roof extractor fan was installed to help air flow for the passengers. At first, the extra heat also damaged some components and insulation was introduced on the exhaust system to remedy this. Volvo also opened up ventilation holes in the engine bay.

## Vehicle operation and performance

The vehicles operate with significant reductions in noise (both inside and outside the cabin) when compared to a conventional diesel counterpart. There are several key areas in which the vehicles have so far failed to match that vehicle performance associated with a diesel counterpart. These include the range of the vehicles and their associated fuel consumption levels, and the poor reliability of the fleet as a whole (see maintenance issues above). The latter can result in around 70% of vehicles performing to an inadequate level at any one time.

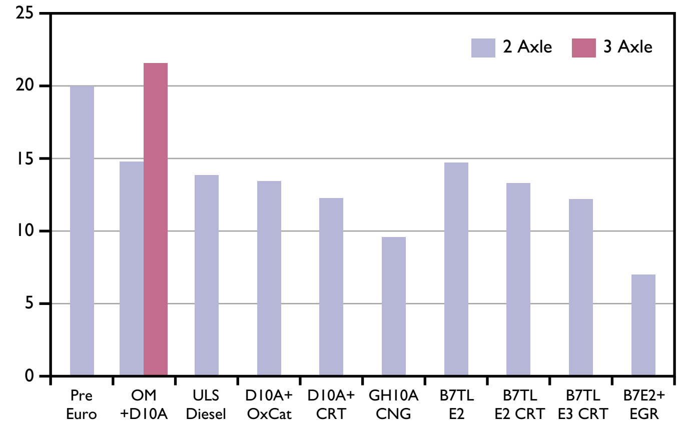
With regard to fuel consumption, the CNG vehicle costs on average about £18 per 100km to run. This includes any benefit obtained from fuel duty rebate. A DERV equivalent vehicle costs about £11.30 per 100km. The associated fuel consumption figures are about 4.4mpg for the CNG vehicle (bearing in mind though that CNG is metered in kg) and 6mpg for a Euro III diesel. The load efficiency is therefore about 13% better for the diesel.

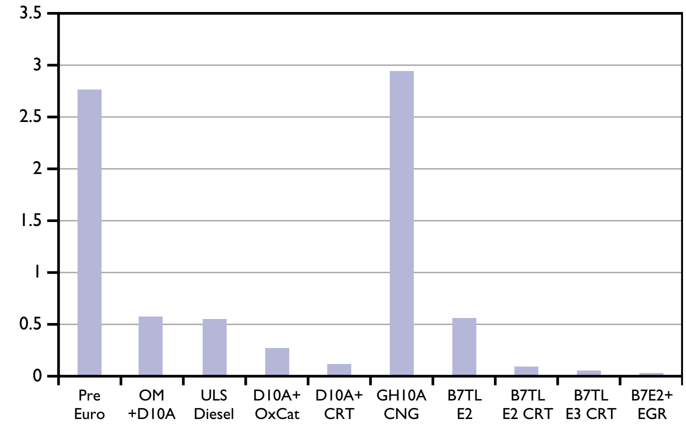
The original operation of the vehicles along Route 529 (a traditionally popular and profitable route between Walsall and Wolverhampton) had to be reduced because of their respective poor reliability. The vehicles are now deployed within a wider scope which detracts from their sole use on a route with high business risk. Their operation is also restricted of course by their range constraints.

When a CNG vehicle has to come off the road due to a fault,, a diesel reserve bus is usually deployed. The problem obviously affects vehicle kilometres covered by the fleet which in turn is detrimental to maintaining the standards of service provision imposed on TWM by the local Traffic Commissioner and as part of their contract. Although the CNG vehicles may have been the cleanest of their time when they were first introduced (about 6 years ago), they now face stiff competition from equivalent diesel powered vehicles (eg. Euro III fitted with CRT) and therefore are deemed inferior in terms of their overall emissions reduction performance. NOx benefits are the only real advantage given by these buses.

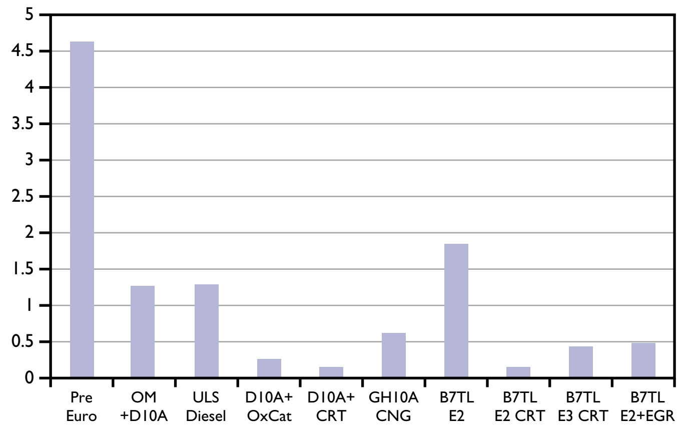
The following charts compare the emissions performance of the Volvo GH10A 245 alongside a variety of other buses.

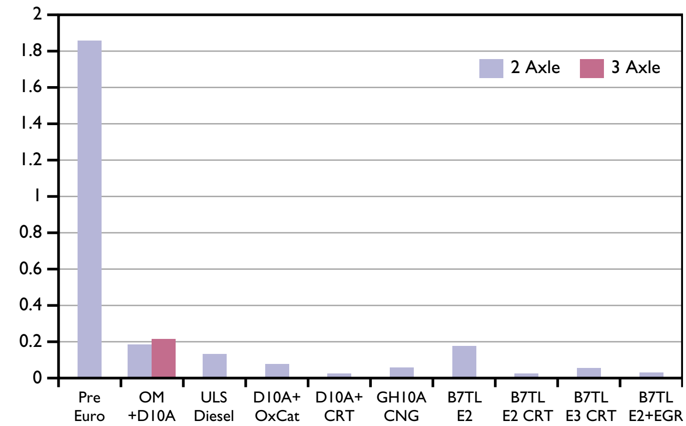
NOx Emissions (g/km): London Route 159; HC Emissions (g/km): London Route 159



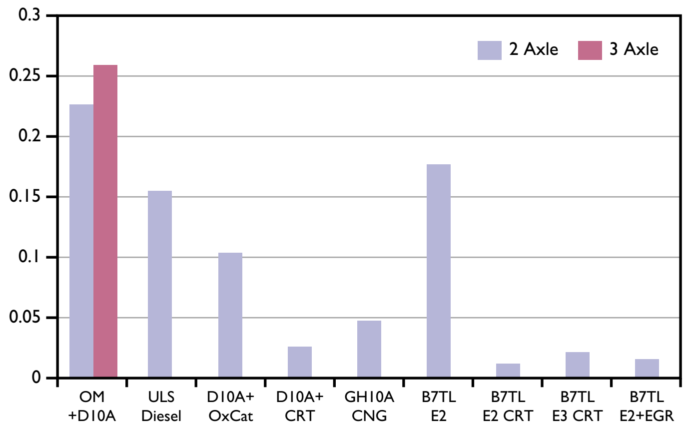




CO Emissions (g/km): London Route 159; $PM_{10}$ Emissions (g/km): London Route 159

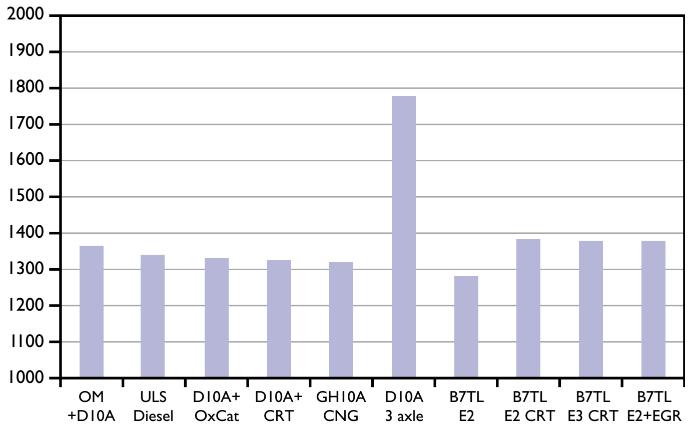



$PM_{10}$ in close up (g/km): London Route 159




$CO_2$ Emissions (g/km): London Route 159




Source: Volvo Bus Ltd

## Next steps

TWM originally signed up for a 10-year contract to run the CNG buses. This however included a clause enabling them to pull out after 5 years if it was deemed the vehicles were too uneconomical. Even though consideration was given to the various negative issues, it was decided to continue with their deployment for a variety of reasons. For example, the image and political will tied up in their existence was too important to eliminate. Also, improvements in performance from re-engineering are worth monitoring to see how well the vehicles perform in the near future. Drivers are happy with the vehicles and passenger perception has now been positively stabilised.

Vehicle life-span for a conventional diesel counterpart vehicle would normally be about 15 years. TWM intend to run the CNG vehicles for the 10 year contract, whereupon if performance levels compared to modern diesel technology are not at least the same (which is unlikely), they will consider converting from CNG to diesel technology and running the vehicles for a further 5 years before final replacement. TWM could have also incurred a penalty charge from British Gas for pulling out of the 10-year contract, another reason for keeping the CNG operation going.

TWM have no current plans to expand the CNG fleet, but they are looking into the possible introduction of diesel/electric hybrid technology in association with the Low Carbon Vehicle Partnership. It is intended that this will reduce the higher $CO_2$ emissions for which CNG vehicles can be noted.

# Portsmouth – Mercedes Benz Electric Hybrid Vehicle

## Contact information

| | |
|---|---|
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## Specification:

- Mercedes 609 minibus converted to a 709 specification and equipped with a prototype diesel electric hybrid drive operating through a two-way clutch. The vehicle was able to drive on diesel power, diesel electric power, or pure electric power at the flick of a switch;
- Re-conditioned Mercedes OSM 364 naturally aspirated 3.9 litre diesel engine developing 66kW at 2,800 rpm;
- Pre-Euro I classification;
- 13 lead acid batteries of 100 Amp hour capacity;
- Shunt wound 216 Volt DC electric motor with a peak capacity of 20kW;
- Seating capacity for 20 passengers;
- GVW of 5,100kg.

## Introduction

As part of the European ENTRANCE project which commenced in 1994, a diesel-electric hybrid bus trial operating in Portsmouth was constructed and evaluated by the Transport Research Laboratory, Hampshire County Council and the Universities of Southampton and Portsmouth. The project aimed to assess the energy consumption and environmental benefits from running such a vehicle. This was measured in terms of both behavioural and economic analyses and formed part of an integral application of measures to raise awareness of energy and environmental issues in the areas of Portsmouth and Southampton.

The trial was co-ordinated by Hampshire County Council, Portsmouth City Council, Provincial Buses (a subsidiary of First Bus) and Hybrid Vehicles Ltd in order to determine the potential for diesel-electric hybrid application in passenger transport.

## Testing with drive cycles

Since the construction and conversion of the hybrid bus were funded by a three-year European programme, a great deal of innovative work was carried out in the design, conversion and operating stages, involving the partners in many processes which had never previously been attempted on a revenue earning bus. After a change in ownership of the bus company in Portsmouth and the need to re-specify the trial, work on the hybrid bus started during 1996. Because of the need to produce results for the conclusion of the ENTRANCE project in early 1998, it was necessary to commence monitoring and evaluation whilst a number of teething problems were still being ironed out.

The vehicle could not be tested using any of TRL's specially developed transient test cycles because the electric motor had insufficient power to complete them. There were therefore only limited cycles that could be used, namely:

- An adapted test cycle which allowed utilisation of the hybrid mode;
- A constant 15km/h speed;
- A constant 30km/h speed.

The electric mode could only complete one of nine tests regarding the hybrid cycle because of the electric motor overheating. All tests were however completed when running in the diesel mode.

## Staff training and vehicle maintenance

From the reporting done for the trial, there was no information on maintenance issues due to the fact the vehicle had been out of service for some period of time. Some problems were incurred however during the trial period with unreliability issues such as the electric motor overheating and cutting out, therefore preventing the completion of some tests. To overcome these problems especially with the hybrid cycle, the Portsmouth diesel ISVR cycle (derived from a study of operating characteristics of buses in the Portsmouth area) was used as a foundation and then all of the inherent speeds were halved and the length of the cycle truncated. This then enabled the electric motor to complete the test.

## Vehicle operation and performance

Results obtained for the vehicle in electric mode were calculated from the amount of electricity required to charge the batteries back up to full power after every test. Emission factors were then used to derive the emissions from associated power production. The table below shows that emissions were highest during the hybrid cycle and lowest during the constant 30km/h cycle. Using the vehicle in electric mode across all cycles meant lower PM, NOx and CO levels, but higher $CO_2$, $SO_2$ and THC levels.

| | Fuel (l/km) | $CO_2$ (g/km) | CO (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) | THC (g/km) |
|---|---|---|---|---|---|---|---|
| **Hybrid cycle** | | | | | | | |
| Electric | | 1530 | 0.43 | 4.19 | 12.8 | 0.31 | 4.61 |
| Diesel mode | 0.231 | 609.1 | 3.73 | 6.44 | 0.4 | 0.65 | 3.85 |
| % Difference | | +168 | -88 | -35 | +3200 | -52 | +20 |
| **15kph** | | | | | | | |
| Electric | | 857 | 0.24 | 2.35 | 7.18 | 0.17 | 2.58 |
| Diesel mode | 0.152 | 400 | 2.16 | 4.8 | 0.23 | 0.34 | 1.58 |
| % Difference | | +214 | -89 | -51 | +3120 | -50 | +63 |
| **30kph** | | | | | | | |
| Electric | | 684 | 0.19 | 1.87 | 5.73 | 0.14 | 2.06 |
| Diesel mode | 0.091 | 240.8 | 1.45 | 2.45 | 0.1 | 0.2 | 1.04 |
| % Difference | | +284 | -87 | -24 | +5730 | -30 | +98 |

Note: Positive values indicate emissions from the electric mode of operation were higher than the diesel mode.

When comparing the hybrid bus with dedicated diesel vehicles it is important to realise the potential difference in $CO_2$ levels. For example, the Mercedes 709 is the most similar vehicle to that of the test vehicle and in this case study the hybrid produced about half the $CO_2$ produced by the diesel under the same operating conditions. This difference is even more significant when it is considered that $CO_2$ is a derivative of complete combustion and should be roughly in proportion to the amount of fuel used, which for these two vehicles should be about the same. The table below displays the other vehicles used in the comparison.

| Vehicle type | Unladen Weight | Test Weight | Engine Type & Size | Transmission Type | Emission Legislation |
|---|---|---|---|---|---|
| **Hybrid Diesel** | 5100 | 5600 | Mercedes OSM 364 4 litre | Manual | Pre-Euro I |
| **Mercedes 709** | 3860 | 5260 | OM 364 4 litre | Manual | Probably Pre-Euro I |
| **Dennis Dart (No 329)** | 5560 | 7250 | Cummins 6BT | Automatic | |
| **Dennis Dart (No 328)** | 5580 | 7260 | Cummins 6BT | Automatic | |

The table below sets out the emissions comparison between the hybrid and other vehicles. Other factors such as driver behaviour and the increased sensitivity of the levels of non-$CO_2$ emissions to changes in engine specification and maintenance, for example could account for other differences in emissions levels.

The advantage of using the hybrid vehicle in electric mode is in its ability to reduce pollution at the local level, notably within the city centre. With no tailpipe emissions, a significant contribution can be made to the local environment which improves the quality of air for public health. Of course, the emissions produced at the power generation end would have more global implications depending on the particular method of generation.

| Cycle | Vehicle type | $CO_2$ (g/km) | CO (g/km) | THC (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|---|
| **Contant 15kph** | Hybrid Diesel | 400 | 2.16 | 1.58 | 4.8 | 0.23 | 0.34 |
| | Mercedes 709 | 713 | 9.21 | 0.58 | 2.1 | 0.42 | 0.29 |
| | Dennis Dart 329 | 1196 | 8.5 | 1.81 | 3.74 | 0.47 | 0.36 |
| | Dennis Dart 328 | 981 | 6.3 | 1.62 | 3.11 | 0.49 | 0.31 |
| **Contant 30kph** | Hybrid Diesel | 240.8 | 1.45 | 1.04 | 2.45 | 0.1 | 0.2 |
| | Mercedes 709 | 461 | 3.04 | 0.26 | 1.58 | 0.29 | 0.14 |
| | Dennis Dart 329 | 857 | 2.37 | 0.64 | 2.6 | 0.37 | 0.2 |
| | Dennis Dart 328 | 700 | 1.98 | 0.73 | 2.25 | 0.29 | 0.17 |

In terms of energy use, the hybrid cycle showed that the electric mode enabled less consumption, but in the other two constant speed tests the diesel mode came out with the better economy. A related outcome, which affected its operational flexibility, was the need to reduce the number of passenger seats in the bus from 25 to 20 to compensate for the additional weight of the electric motor and batteries. The vehicle was certified by the vehicle examiner for passenger carrying use, but only after the rear seats had been taken out of use, which clearly reduced the potential for this bus to inter-work on other busy city services. This result was unavoidable with a vehicle conversion, but would need to be taken into account in designing a bespoke hybrid bus.

## Next steps

Unfortunately, the adaptation of the real-life Portsmouth drive cycle to accommodate the ability of the electric motor meant that realistic conclusions could not be made in terms of the relative merits in comparison to diesel. An insight into the potential for hybrid drives was however established, especially when considering the ensuing improvements in technology to overcome the problems experienced in this study.

The operator did supply some operational data after the vehicle was trailed on Route 14 (connecting the central shopping district and including a bus priority route). The following data was collected in the period between December 1997 and February 1998:

| | |
|---|---|
| **Route length** | **12.8km** |
| **Electric section** | **3.2km** |
| **Total trips sampled** | **104km** |
| **Total mileage** | **855** |
| **Diesel fuel consumption** | **57.18 gallons (14.85mpg)** |
| **Electricity consumption** | **404 units cost £60** |

Note: Average fuel consumption of standard diesel Mercedes Benz 709 is about 16mpg.
Source: Hampshire County Council


Indications from the application of the vehicle in public service suggested it to be popular with drivers and passengers, especially after having rectified many of the teething problems first encountered. The electric mode was used along the route mentioned above (with an extension to the initial distance operated in electric mode) without any problems of battery fatigue.

The vehicle remained in the fleet of First Provincial after the conclusion of the ENTRANCE project and gave sporadic service. The conversion company (Hybrid Vehicles Ltd) ceased trading however some while afterwards and the vehicle was finally disposed of after a period of use as an ancillary runabout vehicle in early 2003.

# Southampton – Dennis Dart CNG Vehicle

**Contact information**

Hampshire County Council


| | |
|---|---|
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## Specification:

- Single-deck 'midi' bus;
- Seating capacity for 35 passengers;
- Standing capacity for 10 passengers;
- Three types of CNG engine were tested: converted, re-engineered and dedicated.

## Introduction

Hampshire County Council, Southampton City Council, Southampton Citybus and British Gas collaborated in a trial of 16 CNG buses operating under the name of 'Eco-Bus'. Within this fleet there were three vehicles that had their existing diesel engines converted to run on CNG, three had their diesel engines exchanged for new CNG engines, and ten were bought in as new dedicated CNG vehicles. The vehicles and conversions were funded as part of the European ENTRANCE project. The vehicles entered service at different times within the period of July 1995 to July 1996. The main indicators to be measured during the trial were for regulated pollutants and $CO_2$; fuel and energy consumption; capital, operational and running costs; and attitudes of users, drivers, and maintenance engineers.

## Infrastructure requirements

A gas filling station was officially launched in July 1996 and is also available for other users of the fuel. British Gas provide the fuel and at the time of the trials, a typical fuel price was assumed to be 27.4p/kg. At the time also, diesel was assumed (and equated) to be about 35.4p/kg (30.1p/litre). Costs exclude VAT because bus operators are exempt and it also includes the fuel duty rebate at the time.

The capital costs associated with the vehicles ranged according to the type of specification mentioned above. The new dedicated vehicles cost about £130,000, this is about 60% more than a conventional diesel counterpart (£80,000). At the time of the project, to install new CNG engines into existing diesel vehicles would have cost about £13,500 each, this compared to replacing with a diesel engine which could cost between £5,000 and £6,000. To convert vehicles to run on CNG (including any changes to the vehicle structure and bodywork) cost about £14,000 per vehicle. In comparison, diesel refurbishment costs between £3,000-£4,000.

## Staff training and vehicle maintenance

At the time, bus company technicians had to undergo additional training in order to meet the standards for gas installation. Drivers also had an additional 3-hour session added to their standard induction package with regard to learning about CNG vehicle operation and refuelling. After the period of initial operation where reliability issues were at the forefront, a warranty partnership between the engine and vehicle manufacturers ensured that these problems did not recur during their prolonged fleet operation.

Although the maintenance procedures for the CNG vehicles were comparable in terms of type and frequency to the diesel vehicles, there were some additional issues specific to the CNG vehicles that should be highlighted:

- The CNG buses have spark-ignition systems (as opposed to compression – ignition with diesel) which means spark plugs have to be replaced twice yearly and high tension cable replaced yearly. Associated costs were £150 per vehicle per year;
- A gas leak check is incurred if there appears to be a pressure drop in cylinders overnight. The check is carried out at least once a year as a formality, thus incurring a cost of at least £15 a year;
- A synthetic lubricating oil is used for the CNG vehicles (as opposed to standard mineral oils for diesels), thus incurring an extra £95 per vehicle per year;
- A one-off cost incurred for optimising the CNG vehicle management system via the use of specialised diagnostic software running on a laptop would at the time of the project, have represented an extra £2,000 which would not be required for a diesel vehicle.

Overall, maintenance costs for the CNG vehicles were found to be about £260 more per vehicle per year when compared to diesels.

## Vehicle operation and performance

Following a period of teething problems and their subsequent rectifying during 1996, the vehicles proved to offer similar reliability to that of their diesel counterparts. One initial issue however was concerned with fuel consumption in that CNG vehicles tended to complete only half the mileage of that covered by the diesel vehicles (68 miles/day compared to 130 miles/day). There was a possible cause for this, namely the longer time taken to fuel vehicles using a slow-fill facility overnight coupled with inadequate pressure to refuel the complete fleet. There was also a fast-fill pump for daytime refuelling in between services, but this was not generally utilised because of disruption to vehicle schedules. The dedicated CNG vehicles could generally complete a 12-hour day's operation in service.

The CNG vehicles did however tend to use between 50-80% more fuel than the diesel counterparts. This can be explained in terms of the additional weight carried by CNG vehicles with the fuel storage cylinders, and also the inherent increased efficiency of diesel engines (compression ratios are higher for diesel engines than CNG, thus making them more efficient). The table below displays the different vehicles used for the comparison of emissions measurements. Note that emissions measurements (carried out on the TRL test track) were only taken for four CNG powered vehicles, ie. one conversion, one re-engineered and two dedicated versions.

| Vehicle number(s) | Fuel | Weight (kg) *unladen* | *test weight* | Engine Type | Engine Capacity |
|---|---|---|---|---|---|
| **328**<br>**329** | diesel | 5560<br>5580 | 7250<br>7260 | Cummins 6BT | 5.9 litres |
| **305** | CNG (conversion) | 6060 | 7850 | Cummins 6BT | 5.9 litres |
| **301** | CNG (re-engineered) | 6170 | 7910 | Cummins 5.9G | 5.9 litres |
| **335**<br>**337** | CNG (dedicated) | 6930<br>6930 | 8680<br>8670 | Cummins 5.9G | 5.9 litres |

Source: Hampshire County Council

The following series of six tables presents the emissions measurements taken for the four CNG vehicles and two diesels. To summarise, some pollutants from the CNG vehicles were actually lower than that for the diesels, eg. PM and $SO_2$, but emissions of $CO_2$, CO, THC and NOx from the CNG vehicles tended to be higher than for diesel. The diesel buses used in this trial were arguably clean for their time so put the CNG vehicles at an immediate disadvantage. It should be said however that diesel technology is even better these days and this is the standard at which CNG vehicles must compete with now if they are to prove viable within the industry.

**Average emissions from Southampton Citybus 328 (diesel)**

| Drive cycle | $CO_2$ (g/km) | CO (g/km) | THC (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|
| **15 km/h** | 1196 | 8.50 | 1.81 | 3.74 | 0.47 | 0.36 |
| **30 km/h** | 857 | 2.37 | 0.64 | 2.60 | 0.37 | 0.20 |
| **45 km/h** | 667 | 2.13 | 0.38 | 1.71 | 0.27 | 0.15 |
| **60 km/h** | 628 | 1.10 | 0.25 | 1.58 | 0.26 | 0.21 |
| **BP** | 1074 | 3.69 | 0.89 | 3.58 | 0.42 | 0.15 |
| **TNO** | 1222 | 2.70 | 0.60 | 3.85 | 0.56 | 0.26 |
| **ISVR Diesel** | 1305 | 7.32 | 0.83 | 4.00 | 0.56 | 0.27 |
| **ISVR CNG** | - | - | - | - | - | - |

Source: Hampshire County Council

**Average emissions from Southampton Citybus 301 (re-engineered CNG)**

| Drive cycle | $CO_2$ (g/km) | CO (g/km) | THC (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|
| **15 km/h** | 3480 | 18.6 | 11.8 | 6.93 | 0.15 | 0.19 |
| **30 km/h** | 1617 | 8.50 | 11.9 | 2.81 | 0.06 | 0.06 |
| **45 km/h** | 965 | 4.78 | 6.45 | 0.66 | 0.02 | 0.10 |
| **60 km/h** | 715 | 3.33 | 4.48 | 0.59 | 0.02 | 0.04 |
| **BP** | 2200 | 21.5 | 11.5 | 3.59 | 0.08 | 0.12 |
| **TNO** | 2183 | 24.2 | 25.1 | 4.75 | 0.10 | 0.12 |
| **ISVR Diesel** | 2684 | 28.2 | 19.4 | 5.43 | 0.15 | 0.08 |
| **ISVR CNG** | 3103 | 36.7 | 23.4 | 6.51 | 0.17 | 0.18 |

Source: Hampshire County Council

**Average emissions from Southampton Citybus 329 (diesel)**

| Drive cycle | $CO_2$ (g/km) | CO (g/km) | THC (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|
| **15 km/h** | 981 | 6.30 | 1.62 | 3.11 | 0.49 | 0.31 |
| **30 km/h** | 700 | 1.98 | 0.73 | 2.25 | 0.29 | 0.17 |
| **45 km/h** | 594 | 1.19 | 0.41 | 1.34 | 0.25 | 0.16 |
| **60 km/h** | 556 | 0.68 | 0.25 | 1.47 | 0.25 | 0.15 |
| **BP** | 798 | 3.30 | 0.38 | 3.08 | 0.27 | 0.26 |
| **TNO** | 858 | 3.56 | 0.73 | 2.58 | 0.37 | 0.31 |
| **ISVR Diesel** | 1126 | 2.92 | 0.86 | 3.70 | 0.51 | 0.28 |
| **ISVR CNG** | 1230 | 2.98 | 0.89 | 3.84 | 0.60 | 0.27 |

Source: Hampshire County Council

**Average emissions from Southampton Citybus 335 (dedicated CNG)**

| Drive cycle | $CO_2$ (g/km) | CO (g/km) | THC (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|
| **15 km/h** | 3188 | 19.0 | 14.7 | 7.20 | 0.20 | 0.28 |
| **30 km/h** | 1408 | 10.4 | 8.67 | 1.77 | 0.04 | 0.29 |
| **45 km/h** | 745 | 5.24 | 9.59 | 0.55 | 0.02 | 0.14 |
| **60 km/h** | 562 | 3.14 | 8.16 | 0.34 | 0.01 | 0.07 |
| **BP** | 1894 | 12.0 | 13.0 | 2.60 | 0.08 | 0.15 |
| **TNO** | 2059 | 16.0 | 23.8 | 4.71 | 0.10 | 0.09 |
| **ISVR Diesel** | 2114 | 16.4 | 20.5 | 4.38 | 0.10 | 0.29 |
| **ISVR CNG** | 2509 | 18.8 | 22.4 | 5.32 | 0.14 | 0.28 |

Source: Hampshire County Council

**Average emissions from Southampton Citybus 305 (converted CNG)**

| Drive cycle | $CO_2$ (g/km) | CO (g/km) | THC (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|
| **15 km/h** | 2453 | 18.3 | 37.8 | 1.69 | 0.04 | 1.80 |
| **30 km/h** | 1338 | 8.53 | 17.3 | 4.12 | 0.09 | 0.04 |
| **45 km/h** | 1039 | 4.23 | 6.23 | 7.37 | 0.13 | 0.02 |
| **60 km/h** | 730 | 2.52 | 2.38 | 9.03 | 0.12 | 0.10 |
| **BP** | 2047 | 30.4 | 21.1 | 7.99 | 0.17 | 0.16 |
| **TNO** | 2176 | 29.4 | 16.8 | 16.3 | 0.29 | 0.12 |
| **ISVR Diesel** | 2612 | 41.0 | 19.0 | 15.5 | 0.30 | 0.48 |
| **ISVR CNG** | 3262 | 47.0 | 23.1 | 16.1 | 0.35 | 0.23 |

Source: Hampshire County Council

**Average emissions from Southampton Citybus 337 (dedicated CNG)**

| Drive cycle | $CO_2$ (g/km) | CO (g/km) | THC (g/km) | NOx (g/km) | $SO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|
| **15 km/h** | 2897 | 24.6 | 15.7 | 6.74 | 0.18 | 0.21 |
| **30 km/h** | 1324 | 9.50 | 10.9 | 1.75 | 0.05 | 0.08 |
| **45 km/h** | 781 | 3.94 | 6.83 | 0.61 | 0.02 | 0.13 |
| **60 km/h** | 520 | 2.54 | 5.08 | 0.32 | 0.01 | 0.04 |
| **BP** | 1754 | 11.0 | 10.6 | 4.24 | 0.09 | 0.24 |
| **TNO** | 1821 | 19.4 | 24.9 | 4.77 | 0.11 | 0.16 |
| **ISVR Diesel** | 2215 | 18.8 | 18.6 | 5.19 | 0.11 | 0.11 |
| **ISVR CNG** | 2517 | 18.9 | 19.0 | 5.35 | 0.10 | 0.32 |

Source: Hampshire County Council

The following table summarises the emissions in terms of combined cycle scenarios.

| Emission | Diesel emission rate (g/km) | Dedicated CNG Factors* | Re-engineered CNG Factors* | Converted CNG Factors* |
|---|---|---|---|---|
| | | ISVR cycles | | |
| $CO_2$ | 1216 | 2.07 | 2.55 | 2.68 |
| CO | 5.12 | 3.68 | 7.16 | 9.18 |
| THC | 0.86 | 24.2 | 27.3 | 26.9 |
| NOx | 3.85 | 1.39 | 1.69 | 4.18 |
| $SO_2$ | 0.54 | 0.22 | 0.31 | 0.65 |
| PM | 0.28 | 1.07 | 0.64 | 0.82 |
| | | 30 km/h and 45 km/h steady speed cycles | | |
| $CO_2$ | 705 | 1.51 | 1.83 | 1.69 |
| CO | 1.92 | 3.79 | 3.46 | 3.33 |
| THC | 0.55 | 16.4 | 16.7 | 21.5 |
| NOx | 1.98 | 0.59 | 0.88 | 2.91 |
| $SO_2$ | 0.29 | 0.11 | 0.14 | 0.39 |
| PM | 0.17 | 0.95 | 0.49 | 0.20 |
| | | 30 km/h and 45 km/h steady speed cycles | | |
| $CO_2$ | 939 | 1.88 | 2.26 | 2.08 |
| CO | 3.36 | 3.90 | 5.43 | 6.75 |
| THC | 0.76 | 19.0 | 18.6 | 23.5 |
| NOx | 2.89 | 1.21 | 1.31 | 3.38 |
| $SO_2$ | 0.41 | 0.21 | 0.23 | 0.46 |
| PM | 0.24 | 0.76 | 0.48 | 0.64 |

* Factors greater than 1 indicate a higher emission rate than the diesels and vice versa.
Source: Hampshire County Council

## Next steps

Although the outputs of these trials could be deemed relatively negative for the CNG case, it should be remembered that both CNG and diesel technology have moved on markedly since the trial. The use of devices such as catalytic converters to reduce CO and THC by about 50% are now commonplace.

The issue of increased fuel consumption is still a prominent one, but with the subsequent opportunity to introduce lightweight composite gas tanks and encourage the optimisation of engines and control systems through recent technological developments, the situation could be significantly improved.

The extent of positive approval to the vehicles during the trials and in current times should also not be underestimated. The public seem to be very open to any effort made on behalf of operators and the authorities to try and improve local air quality, and with CNG vehicles this can go hand-in-hand with improvements in noise reduction also.

The fleet of CNG buses provided many years of public service in Southampton, although the earlier conversions have now been withdrawn. The dedicated CNG buses still provide trouble-free service on city bus services seven years after their construction.

# Future Developments in Vehicles and Cleaner Fuels

The Government's 'Powering Future Vehicles' strategy, together with the work of the Low Carbon Vehicle Partnership, is aimed at encouraging the development and uptake of new low carbon technologies in the vehicle market. Buses form a key sub-sector within this market, where it is hoped that progress can be made fairly rapidly. Two main technical areas are likely to form the basis of future developments. These are hybrid buses and hydrogen fuel cell buses. EST has produced a review of future developments in a recent publication[16].

## Hybrid buses

The development of hybrid vehicle technologies is being undertaken by several motor manufacturers for passenger car applications. Hybrid vehicles combine an electric battery with the power and performance of a conventional engine. The hybrid vehicles that are currently on the market are petrol engined, mainly in the form of cars and light goods vehicles. The development of these technologies for larger diesel vehicles such as buses, is less advanced than that of lighter duty vehicles. Diesel hybrid buses would possibly be ideal for city and urban driving conditions because they could operate on their zero emission electric battery in congested traffic. However, diesel hybrid buses are still largely in demonstration, and therefore data on their operating costs, performance and reliability are not readily available.

In demonstrations, some US trials of diesel hybrid buses are showing at least a 30% improvement in tailpipe $CO_2$ emissions. In addition, the particulate and NOx emissions from diesel are likely to improve significantly with new particulate trap and de-NOx technology, so that the combination of these advances and hybrid technology could enable vehicles with significantly better environmental performance to be developed. However, the economics of hybrid vehicles operations have yet to be demonstrated as being competitive with conventional vehicles – in particular the capital costs of the buses involved in some of the current demonstrations projects are currently twice that of an equivalent conventional bus. Hybrid vehicles are seen by some as a possible 'bridge' from pure internal combustion-engined vehicles to fuel cell vehicles. Others think that they will form part of the longer-term solution. Long term inherent design cost differentials can be expected to reduce with economies of scale. The cost of the conventional automatic bus transmission can be offset against the cost of new components in the hybrid drive-train.

[16] Energy Saving Trust: 'Pathways to future vehicles – a 2020 strategy', London, 2002

## Hydrogen

Hydrogen has the highest energy density and potentially the least environmental impact of all chemical fuels. Its chemical energy can be released through combustion in an internal combustion engine with very few polluting effects. The gas can be stored on-board the vehicle in compressed or liquid form and can be used in bi-fuel or dedicated gas engine vehicles. When burnt in this way, water is left over as the main residue, together with a small quantity of nitrogen oxide. This can be controlled through balancing the air supply and through the use of a simple catalytic converter.

Hydrogen gas internal combustion engines have been successfully demonstrated around the world over the last 20 years. There are around 20 experimental vehicles currently in use, mainly in Germany. There are no disadvantages in principle to acceleration, vehicle performance, operating range and overall operation compared with conventional petrol and diesel fuelled vehicles. On-board reformers of conventional fuels are also a possibility for generation of hydrogen.

The gas is highly buoyant in air, non-toxic and on combustion releases a large amount of energy per unit mass (120MJ/kg compared with 42MJ/kg for petrol). On board storage of hydrogen presents a major challenge. Its low density means that a very large fuel tank is needed, and the solution is to either compress or liquefy the gas to reduce its volume. Compression is the most cost-effective approach, the gas being stored in cylinders at about 200 bar (3,000psi). Cryogenic systems have been demonstrated which retain the low temperature required for hydrogen liquefaction at -253°C. Both methods require energy to compress or liquefy the hydrogen. The energy required for liquefaction is much greater. No distribution network currently exists for hydrogen for transport use. Planning permission would be required for hydrogen re-fuelling facilities.

## Fuel Cell Electric Vehicles

A fuel cell is an energy conversion device, which comprises an electrolyte sandwiched between two electrodes. By combining hydrogen and oxygen to form water, a fuel cell converts chemical energy into electricity and heat. In the transport application, the electricity is used to power an electric motor, which then drives the vehicle in a similar fashion to a Battery Electric Vehicles. A key point of difference, however, is that a fuel cell draws on an external fuel supply and will operate for as long as the fuel is supplied. They do not suffer from the range problem of battery electric vehicles. By contrast, batteries store their fuel supply internally, and must be disposed of or recharged when the fuel is exhausted. Both batteries and fuel cells currently have a lifetime that is less than a conventional engine. The associated costs must be factored into any comparison of motive power over the lifetime of the vehicle.

Fuel cells are capable of high-energy conversion efficiency which compares favourably with the thermal efficiency of petrol and diesel engines. A fuel cell engine is also very efficient at low loads such as those in urban traffic conditions. The main interest in their development for transport applications is their capability of operating with zero emissions at point of use. As the fuel cell will only replace the battery in an electric bus, electrically efficient drive-lines will be required of the type described earlier in this guide. In particular the storing of regenerative power in a power store will reduce the power demand and hence the cost of the fuel cell. Such electrical drive-lines therefore provide a generic technology which needs to be developed in parallel with fuel cells. This will allow the industry to optimise the drive-line system and develop the necessary service and maintenance techniques.

Fuel cell buses look likely to reach the commercial market sooner than cars or heavy goods vehicles. This is because bus designs allow sufficient space to accommodate the fuel cell stacks, fuel storage and any necessary on-board fuel reforming. Buses also operate from and pick up fuel from depots, and do not need any new fuelling infrastructure to be available across the road network. Thirty buses, based on the DaimlerChrysler 'Citaro' model design, are being piloted in 10 cities across the EU. Three of these buses will be operated in London between 2003 and 2005. The buses will be refuelled with compressed hydrogen that will be transported to a filling station in liquid form by road tanker. The prototype hydrogen fuel cell buses currently available cost about £1M – nearly ten times the price of a conventional diesel bus. The trials of these fuel cell buses will enable better information on operating experience, costs and reliability to be obtained, and this in turn should help decision makers to undertake how much potential there is for fuel cell technology in the future.

The fuel cell buses are part of the Clean Urban Transport for Europe project, and for further details see: www.cute-eu.net and www.daimlerchrysler.com

## Hydrogen production

An important consideration for hydrogen-fuelled vehicles is the actual source of hydrogen. Current methods include hydrolysis of water, which requires a large input of electricity. If the electricity is generated from fossil fuels, then the net greenhouse gas and other emissions may be greater than delivering the equivalent motive power for the vehicle via an internal combustion engine using a conventional transport fuel such as diesel. If the electricity is from renewable energy sources, so-called 'carbon free' electricity, then hydrogen from electrolysis is an 'ultra low carbon' option – so in the long term renewable electricity for hydrogen may well be the most suitable choice for low carbon transport.

However, in the UK's current energy system renewable electricity saves more carbon by displacing fossil fuels used in electricity generation than would be saved by using renewable electricity to produce electrolytic hydrogen to power vehicles. Fuelling all road transport using electrolytic hydrogen from renewable electricity would require a doubling of electricity supply and a twenty-fold increase in the amount of renewable electricity generation in the UK.

Other methods of producing hydrogen include reforming from gas, and this is currently the cheapest option. If the hydrogen is used in a fuel cell vehicle this will give modest improvements in carbon emissions over an efficient diesel hybrid, and hence gas is the most likely feedstock for initial demonstration of hydrogen as a transport fuel. The reformer could even be on-board the vehicle.

Another option is hydrogen from biomass, where there are a number of possible technical routes, including via bioethanol or biomethanol (see below). This route is eventually likely to be cheaper than electrolytic hydrogen, and the carbon savings of advanced biofuel technologies are broadly similar to using biomass for power or heat. Hence this is a better route to hydrogen than electricity in the medium term, but a key issue for UK resources may be land availability, and a major contribution to the transport sector will require high yield crops.

## Bioethanol

Bioethanol can be produced from biomass feedstocks such as starch crops (eg. cereals or potatoes), sugar crops and short rotation coppice materials. Wheat is a potential feedstock, and the process involves milling, conversion to sugar, fermentation, distilling and dehydration[17]. Bioethanol is liquid at room temperature and can be used as an octane enhancer for petrol. It has a higher octane rating than petrol, allowing higher engine compression ratios. Cold starting is a problem, so a 5-15% petrol blend is commonly used. Bioethanol is most likely to be used as a petrol replacement fuel (or in blends) and is not a candidate for replacing diesel.

[17] For a comprehensive description of bioethanol production, see 'The impacts of creating a domestic UK bioethanol industry', East of England Development Agency, July 2003.
[18] See the British Sugar web site on bioethanol at www.britishsugar.co.uk/bsweb/biofuel

Current estimates of the production costs of bioethanol from UK crops are that the fuel would require at least a 25p/litre fuel duty reduction in order for it to compete with the retail price of petrol[18].

Bioethanol has been developed as a motor fuel and widely used in Brazil with sugar cane being used as the feedstock, which has involved a Government programme and subsidies. Annual production has been in excess of 10M tonnes, and several million vehicles have operated on bioethanol.

In Sweden, a programme to demonstrate the use of ethanol as a fuel for buses and other vehicles has been underway since 1991. More than 300 buses have been operated in various cities and rural areas around the country. Tests with these buses show that levels of regulated as well as unregulated emissions are well below those for the diesel fuelled equivalent vehicle. Ethanol is seen as a viable fuel option in Sweden, although it cannot yet compete economically with fossil fuels.

## Market up-take of fuelling options

A recent SMMT report gives an indication of the potential 'roll-out' of future fuelling options in the UK vehicle markets[19]:

**Soft options:**

- ULSD is being used by many buses in the UK already, well before the mandatory requirement being imposed by European legislation;
- Emulsion fuels are being tested now and serve as a major stepping stone to improving local air quality but still using conventional fuel;
- Fuel enhancers are a little more behind in the UK (eg. bio-fuel additives) with their application being considered more so for sustainable power production instead.

**Intermediate options:**

- Diesel hybrids are being developed and tested in the UK now;
- Bio-fuels could develop into an intermediate example of application once costs reduce and their selling point as being carbon-neutral could prove attractive;
- With its low fuel prices at present (due partly to the current tax regime), LPG is a possible option for encouraging the bus industry to make the transfer from conventional fuel to alternative. Fuel supply, infrastructure and vehicle performance issues have however stunted its progress within bus application, this in contrast to the car market.

**More information**

For more information on the Swedish programme, consult the CADDET Technical Brochure 62, 1997 – Ethanol powered buses reduce vehicle emissions in Stockholm, see ***www.caddet-re.org***

**Mainstream development:**

- Although natural gas has already been tested in a few sites across the UK, the service still requires further development in order to gain the reputation and trust of the bus industry as a whole. Throughout Europe, where there is no equivalent to the BSOG, natural gas buses are gaining market share;
- Again, LPG is becoming well-known in the car and light van market, it is still going through the stages of development for larger commercial vehicles;
- Electric-only operating buses are still in the early stages of development, with issues of reliability and range at the forefront. Whether they will ever prove to be a more realistic alternative to the combustion engine vehicles will depend on whether the vehicle performance, charging duration and costs can be refined to form an attractive package.

**Future:**

- Hydrogen, both as an integral part of a fuel cell or as a combustion fuel, is considered to be an option for the longer term, should ongoing research and development prove successful. Vehicles produced recently are mostly representative of prototype models only and are far from becoming viable vehicles for commercial operation.

[19] Society of Motor Manufacturers and Traders: 'Towards a shared vision – future fuels and sustainable mobility', London, 2002.

# Action Plan

## Investment Decision

Operators need to be satisfied that sufficient information is available for them to make the necessary investment decisions. Some of the experiences outlined in Section 4 should help, but clearly the experiences are relatively limited and not necessarily relevant to every operator's service requirements. However, the case studies and other information are a useful first step in assessing the benefits and costs of clean fuel bus operation.

## Recommendations

### Development of Product Specification

The key issues in operating cleaner fuel buses are:

- What is the purchase cost of cleaner fuel vehicles compared with the diesel equivalent, and the resale value of buses after their first operational ownership;
- What are the full life costs of cleaner fuel vehicles;
- What are the maintenance and depot requirements and how much additional maintenance costs are involved;
- What are the running costs in pence per kilometre;
- What are the impacts of fuel tax and Bus Service Operators Grant on costs and the perception of how these might change;
- What are the refuelling requirements, and the land-use, depot facilities and health and safety considerations;
- What driver and maintenance staff training is required, including health and safety training;
- Whether the internal configuration of the vehicles might interfere with passenger carrying capacity;
- Whether the acceleration, deceleration and other operating characteristics will have an impact on operating schedules;
- Whether the vehicles can meet current or future emissions standards, and any local authority emissions restrictions in Air Quality Management Areas or Low Emission Zones.

### Tenders and specifications

There is a small number of manufacturers able to serve the British bus industry, and an even smaller number able to supply cleaner fuel technology. A full market analysis of potential suppliers should be undertaken by the bus operator before developing the product specification, as this will help to ensure that it is realistic and deliverable.

The development of the tender documentation should reconcile the requirements of the commissioning authority and the vehicle operators with the product capabilities of the manufacturers. Customisation of vehicles may well lead to a better product that better matches the requirements of the commissioning authority and/or vehicle operator. However an extended delivery time and/or increased purchase price might outweigh the benefits to be realised by a closer fit with requirements.

If a service is to be subsidised by the local authority (or Transport for London or a Passenger Transport Executive), the vehicle specification should be placed within the normal tendering documentation, and potential vehicle operators allowed to provide tenders costed upon the basis of purchasing and operating the required vehicles in service for the length of the contract period. For example, early termination clauses may penalise cleaner fuel bus operation due to the costs of the initial capital investment that might be incurred at the start of the contract. If a service is to be operated on a commercial basis, the details of the vehicle specification should be included as a priority within the Quality Bus Partnership protocols (see Appendix 3).

Before developing a vehicle specification, and certainly before purchasing any cleaner fuel vehicles a full assessment of their performance should be undertaken by reviewing the wide range of material available regarding the 'real world' application of alternative fuel technologies both in the UK and elsewhere. In this way it is possible to glean an idea of the potential benefits and pitfalls of investment in clean vehicle technology, and an appreciation of which type of vehicles might be most appropriate for the commissioning authority's situation and requirements.

### Cost Benefit Analysis

A full socio-economic benefit analysis should be undertaken of the cleaner bus investment scheme taking into account all available and projected financial information, together with estimates of monetary values for the anticipated environmental, social and other external impacts. Unfortunately, the value of all the benefits does not accrue through the farebox to the typical bus operator in the UK.

**How to demonstrate benefits of proposed cleaner fuel technology**

The benefits of proposed cleaner fuel technology can only adequately be addressed by setting up a full monitoring regime, which will allow measurement of the following:

- Loss of passenger carrying payload;
- Capital costs of vehicle and refuelling infrastructure;
- Emissions (air emissions and noise);
- Fuel consumption;
- Operating Costs (including labour and maintenance costs);
- Driver and passenger perceptions;
- Residents' perceptions.

## Sources of Funding

One of the most important considerations is whether there are sources of funding to help support an investment in cleaner fuel buses. There are several government-funded programmes that are available for cleaner fuel vehicle projects. Financial assistance in the purchasing of cleaner fuel vehicles, and support for R&D projects can be obtained from these programmes, which usually involve an element of cost-sharing between the public and private sectors. For further information about TransportEnergy, and the grant funding programmes for demonstration projects (New Vehicle Technology Fund and CleanUp Demonstration Programme), alternative fuel vehicles (the PowerShift programme) and emissions controls technologies (the CleanUp programme), visit the TransportEnergy website at www.transportenergy.org.uk

Vehicle manufacturers and fuel suppliers may also have an interest in promoting new technologies, through the use of demonstration and field trial projects. Partnerships with local authorities, bus operators and vehicle and fuel suppliers offer the best prospect of introducing new technologies, since all parties can benefit from a successful collaboration.

**PowerShift (England, Wales, Northern Ireland and Scotland)**

TransportEnergy PowerShift is a programme to help kick start the market for alternative, cleaner fuel vehicles in the UK. The programme, through government grants and assistance, aims to create the conditions for cleaner fuel vehicles to be practically and economically viable.

PowerShift works to break down the barriers to the development of a cleaner fuel vehicle (CFV) market in the UK, which are:

- The lack of refuelling infrastructure;
- The extra initial capital cost of vehicles;
- Misconceptions about vehicle safety;
- Low awareness of the benefits of CFVs;
- Limited numbers and choice of vehicles available.

All applicants seeking grant funding for cleaner fuel vehicles must choose vehicles that appear on the PowerShift Register. The Register is a buyer's guide to cleaner fuel vehicles, and PowerShift sets technical, safety and emissions standards for all the vehicles it helps to fund. It is the only comprehensive source of impartial information available in the UK, and it allows vehicle buyers to make informed choices about the merits of the different cleaner fuel vehicles on offer and provides the basis on which PowerShift grants are offered.

PowerShift is funded by the Government Department for Transport and by the Scottish Executive, and it has also received support from a range of industrial sponsors including Vauxhall, Ford, Peugeot, Toyota, Transco, BG Plc, Volkswagen, Shell, Calor, BP, Mobil and Powergen.

**CleanUp (England, Scotland)**

CleanUp is one of TransportEnergy's programmes to help improve air quality by reducing the tailpipe emissions (primarily NOx and PM) from the commercial vehicle fleet. The aim of the CleanUp programme is to encourage vehicle fleets to retrofit proven diesel emission reduction technologies, such as particulate traps, exhaust gas recirculation and selective catalytic reduction, which reduce the target emissions in the most cost effective manner. Fitting these technologies reduces emissions from key high polluting vehicles operating in urban centres, including buses, taxis, delivery vehicles, refuse trucks and fire appliances. Grant funding of up to 75% of the capital cost is available to support both private companies and public sector organisations to fit approved CleanUp technologies. There is also a CleanUp demonstration programme that provides funding of up to 50% of the projects costs for developing new technologies and helping to bring them to market.

**New Vehicle Technology Fund (England only)**

This Fund is designed to help demonstrate projects involving innovative low carbon powertrain technologies. It is managed by EST on behalf of the Department for Transport. The programme has already part-funded several demonstration projects involving cleaner fuel buses. There are also several demonstration projects currently underway of diesel-electric and other hybrid bus designs. The programme is also providing part-funding for the trials of three fuel cell buses in London.

Funding helps towards the additional cost of preparing a vehicle(s) or engine(s) to take part in a demonstration project. Funding is available from 25% up to a maximum of 50% of the eligible project costs. The percentage awarded will be determined by a funding committee based on EC State Aid funding regulations.

Applicants must be:

1. Companies registered and trading in the UK or a consortium (including manufacturer, fleet and fuel suppliers if appropriate); **or**
2. Other organisations (such as Local Authorities) based in the UK; **or**
3. Foreign owned and multinational companies, providing the intention is to exploit the results of the project in the UK.

Applicants must:

1. Work towards the development of low carbon vehicle technologies by way of cleaner power-trains or engines designed to run on cleaner, alternative fuels;
2. Have the potential for full commercialisation in the UK;
3. Have the potential to deliver significant emissions/environmental benefits;
4. Be utilising market-ready or near market-ready technology that is a significant advance on existing technology on the target vehicles.

Eligible Funding Criteria:

- Up to 50% feasibility costs;
- Up to 50% project set up and management costs;
- Up to 50% design of project specific components and system costs;
- Up to 50% additional components, parts and labour required to operate on the alternative fuel or technology;
- Up to 50% of the calibration, integration and validation costs;
- 100% of emissions testing agreed with EST.

The New Vehicle Technology Fund is part of the 'Powering Future Vehicles' Government strategy, which is supported by HM Treasury, DEFRA, DTI and DfT and which aims to support the transition to a low carbon transport system.

More information on TransportEnergy's CleanUp demonstration programme and the New Vehicle Technology Fund can be found on the TransportEnergy web site at www.transportenergy.org.uk or by emailing demonstrations@est.co.uk

### Foresight Vehicle programme

This is a programme funded mainly by DTI to support research into safer, cleaner, more fuel efficient and less resource intensive vehicles. The programme has recently published a roadmap to set out its vision for the technology and research directions for future road vehicles[20], and the development of hybrid, electric and alternatively fuelled vehicles forms one of the key technology themes set out in this roadmap. For more details of this programme see www.foresightvehicle.org.uk

### Reduced Pollution Certificates

Buses which meet certain emissions standards may be eligible for a Reduced Pollution Certificate, reducing the Vehicle Excise Duty paid by the operator. This can marginally assist in the funding of a project.

### European Union programmes

Some Local Authorities have also used EC programmes such as CIVITAS to support clean fuel bus projects, usually as part of a larger programme aimed at improving the impact of transport on the local environment in their area[21].

CIVITAS is part of the 6th Framework Programme for Research and Technological Development. Within this work programme, the thematic priority 1.6 Sustainable Development, Global Change and Ecosystems, covers the transport and energy activities relevant to the CIVITAS Initiative. The current call for proposals will close on 17 December 2003.

The CIVITAS principle is to support integrated strategies designed and implemented in co-ordination by pairs of cities. CIVITAS II will address ambitious cities which should test implementation strategies for innovative and bold integrated strategy packages of transport policy and fuel/vehicle technology measures that are able to maintain or improve the existing modal split in favour of alternative modes.

CIVITAS II will have some specific focuses on:

- Cities in accession countries, to support them in building-up transition strategies, especially in trying to contain the rapidly increasing car ownership in these cities;
- Medium-sized cities (less than 500,000 inhabitants in the city-region area).

Each proposal should combine the integration of alternative fuels into the city transport system with a wider package of policy measures and tools in order to cover both the transport demand and supply side. Key elements of this integration are:

- Innovative energy-efficient, cost-effective and cleaner public and/or private vehicle fleets for passenger or freight transport (minimum Euro-IV standard) using alternative fuels; and
- The necessary infrastructure, in particular for the storage of the alternative fuels and the specific fuelling equipment.

The focus should be put on short/medium term alternatives, ie. innovative bio-fuels, water-diesel emulsion and natural gas, including hybrid vehicles that use these fuels.

[20] Foresight vehicle technology roadmap', DTI, London, August 2002
[21] See for example, the JUPITER project in Merseyside.

# Conclusions

This guide has drawn together practical experience from several UK and other European sources to provide information and data on various types of clean fuel operations in bus fleets. The guide has shown that fuels, fuel sources and engines are being developed across a wide range of potential alternatives, and major research and demonstration projects are in hand to test and evaluate some of the more advanced alternative fuels and motive systems.

Comprehensive and independently monitored data are, however, difficult to obtain, and comparisons between different fuels inevitably suffer from a lack of consistent test methods and duty cycles. The actual combination of fuel, engine and vehicle has to be considered, because each of these has an effect on the overall performance. Nevertheless, it is possible to draw some broad conclusions about the options that are currently available.

Total operating costs are the prime consideration for bus operators. At present, the use of most alternative fuels imposes additional day-to-day running costs, and additional maintenance costs and capital expenditure, when compared with diesel operation[22]. These additional costs are dependent on the type of fuel used, but the lifetime costs can be around 20-25% greater than diesel buses for LPG and CNG bus operation respectively. The apparent cost penalty is heavily influenced by the current Bus Service Operators Grant system. For battery electric and hybrid buses, the additional lifetime costs are currently between 50-100% greater than diesel. CNG, LPG and battery electric vehicles are moderately cost-effective in reducing NOx emissions, and battery electric vehicles are cost-effective at reducing greenhouse gas emissions. Biodiesel is reasonably cost-effective at reducing greenhouse gas emissions on a life cycle basis, and hybrid electric vehicles are also cost-effective for $CO_2$ reduction. Diesel-hybrid electric vehicles will become increasingly cost-effective for reducing NOx, $CO_2$ and particulates, and are seen as one of the most promising medium to long term options for reducing air pollutants and greenhouse gas emissions.

Hence, although alternative fuels and vehicles offer the potential for emission reductions and, in some cases, performance improvements, the economic incentive to operate cleaner fuel buses is very limited. Local authorities would have to make the decision to encourage alternative fuel buses as part of an environmental policy initiative, and they would have to recognise that there would be cost implications for the bus operator. A means of reducing the financial risk to the operator would have to be found, perhaps involving risk sharing with the local authority and other public or private partners.

In the much longer term, fuel cell vehicles offer the promise of zero or very low vehicle emissions, with performance and range equal to or better than conventional vehicles. However, at present they are not a cost-effective option. The capital costs of vehicles and the refuelling infrastructure will have to be reduced significantly before fuel cell technology can be a cost-effective solution for reducing local and global emissions. The life of the fuel cells themselves will also have to be substantially improved.

The eventual market for alternative fuels and technologies in bus operation will be strongly influenced by:

- The predicted costs and benefits to the customer and operator being commercially acceptable;
- Fuel tax and subsidy arrangements applicable to the UK bus industry;
- Whether there are access restrictions to some urban centres for all but low-emission vehicles;
- How much increasingly stringent European emissions control legislation may favour alternative fuels;
- The extent of other benefits from alternative clean fuels such as performance improvements, quiet operation and improved fuel economy.

[22] Source: 'Report of the Alternative fuels group of the Cleaner Vehicles Task Force', DTI, London, March 2000

# Appendix 1: Information Sources

## Air Quality

'Air Quality Strategy for England, Scotland, Wales and Northern Ireland', (published January 2000) and 1st Addendum (published February 2003), Department for the Environment, Food and Rural Affairs.

'Part IV of the Environment Act 1995 – Local Air Quality Management, Policy Guidance', LAQM.PG(03), Department for the Environment, Food and Rural Affairs, February 2003,

For further information about air quality see the DEFRA website www.defra.gov.uk

## Clear Zones

For further information about the Clear Zones initiative, see the website www.clearzones.org.uk

## TransportEnergy

For further information about TransportEnergy, and the grant funding programmes for alternative fuel vehicles (the Powershift programme) and emissions controls technologies for diesel vehicles (the CleanUp programme), and the low carbon demonstration projects (New Vehicle Technology Fund) see the Energy Saving Trust website at www.transportenergy.org.uk or ring the Hotline on 0845 602 1425.

## Vehicles

'Powering Future Vehicles – the Government strategy', Department for Transport, Department of Trade and Industry, Department of the Environment, Food and Rural Affairs, HM Treasury, July 2002.

'Pathways to Future Vehicles – a 2020 strategy', Energy Saving Trust, April 2002.

The Low Carbon Vehicle Partnership website is www.lowcvp.org.uk, and the Foresight Vehicle website is www.foresightvehicle.org.uk

## Low Emission Zones

'The London Low Emission Zone – Phase 1 report of the Steering Group', Greater London Authority and the Association of London Government, February 2002, websites www.alg.gov.uk and www.london.gov.uk

'Cleaning London's air – the Mayor's Air Quality Strategy', Mayor of London, September 2002, website www.london.gov.uk

## Quality Bus Partnerships

'Quality Bus Partnerships Good Practice Guide', available via the TAS website www.tas-passtrans.co.uk/QBP-GPG.htm

## Reports Produced for Hampshire Country Council

Latham S., Transport Research Laboratory, ENTRANCE Monitoring and Evaluation of the Applications in Hampshire – Alternative Fuels (Portsmouth) D-009, (1998).

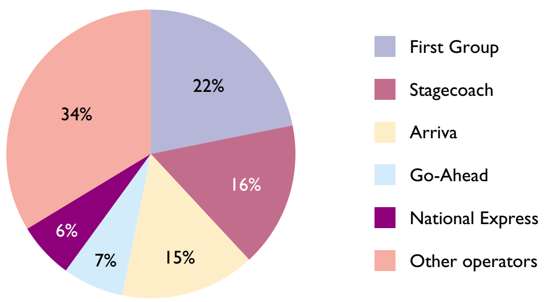
Hickman A.J., Transport Research Laboratory, ENTRANCE Monitoring and Evaluation of the Applications in Hampshire – Alternative Fuels (Southampton) D-007, (1998).

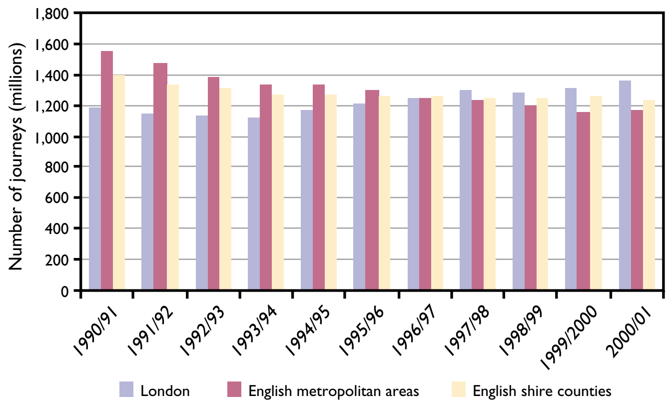
# Appendix 2: The UK Bus Industry

In the UK, commercial bus services account for 82% of those provided in England (outside London), Scotland and Wales (2001/02), whereas in London, all services are provided under contract to Transport for London. In Northern Ireland, bus services are owned and operated by the public sector as a nationalised industry.

There are currently three main large bus operators in the UK and Figure A.1 illustrates the prominence of these companies in the UK bus market. The largest bus company is First Group with 22% of the UK bus market and over 10,000 buses. Stagecoach has a 16% share and over 7,000 buses and coaches, and Arriva has a 15% share and over 6,000 vehicles. Arriva is the largest operator in London with over 20% of the city's bus services.

*Figure A1:* **Share of the UK bus market**




## Travel by bus in the UK

Buses are the most widely used form of public transport in Great Britain. In 2001/02 buses and coaches accounted about 70% of all public transport journeys. The data show:

- In London, patronage has risen by 15% over the last 10 years, with 1.4 billion passenger journeys in 2001/02;
- In the metropolitan areas, patronage has stabilised at around 1.2 billion passenger journeys in 2001/02; and
- In the Shire Counties, patronage has also more or less stabilised at 1.2 billion passenger journeys in 2001/02.

At the national level, local bus services travel over 2,500 million kilometres each year and non-local services over 1,500 million kilometres. Distances travelled by local bus services over the last decade are:

- In London, the distance travelled by buses has gradually risen over the last 10 years to 380 million kilometres in 2001/02;
- In the metropolitan areas, the distance travelled by buses reached a peak in 1994/95 and has since declined to 644 million kilometres in 2001/02, a level similar to that at the beginning of the decade; and
- In the Shire Counties, the distance travelled has gradually risen over the decade and by 2001/02 had reached 1,113 million kilometres.

## Composition of the bus fleet

The stock of buses and coaches has increased fairly steadily over the last 20 years, from 69,000 at the end of 1980 to about 80,000 at the end of 2001/02. In 2001/02, 64,000 of these were single deckers and 16,000 were double deckers. The numbers of double decker buses have been declining as a percentage of the whole fleet.

The average age of the bus fleet has reduced in the last 10 years . Investment in new buses and coaches has been at record levels in recent years, with over 8,300 new vehicles in the fleet in 2002

After rising until the mid-1990s and peaking at 10 years, the average age of the bus and coach fleet has been falling and is now at its lowest level since 1990. One of the initial targets of the Government's 10-Year Transport Plan was to reduce the average age of the bus fleet to eight years by 2001. The target was nearly met, as the average age in mid 2002 was 8.2 years, a reduction of 1.7 years from the 1994 figure. This is an indication of the considerable investment made by operators in recent years and is a result of the many new vehicles registered since 1995 more than compensating for the ageing vehicles still in use.

[23] Source: TAS, 2001
[24] Source: DTLR, Transport Statistics, 2001

# Appendix 3: Legislation

## Vehicle standards legislation

In Great Britain buses (and minibuses and coaches) are subject to a mix of regulations. Some, like the Road Vehicles (Construction and Use) Regulations 1986, govern features that appear on all types of vehicle. Others, like the Public Service Vehicles (Conditions of Fitness, Equipment, Use and construction) Regulations 1981, apply only to Public Service Vehicles (PSVs) – those used for the carriage of fare-paying passengers. Within one set of Regulations there can be requirements for approval, construction, maintenance and use. The result is a regulatory regime which is complex to understand and difficult to apply.

The construction standards of these vehicles are also affected by EC Directives intended to achieve a free market in vehicles. In particular, EC type approval framework Directive 70/156/EC (as amended by Directive 2001/116/EC) lists the technical requirements to be met in order for any whole vehicle to be type approved – the so-called EC Whole Vehicle Type Approval (ECWVTA) regime. This enables vehicles to be registered anywhere in the EU and consequently UK regulations also need to be amended to recognize approved vehicles.

The technical requirements are set out in separate directives, of which about 40 will apply to buses, minibuses and coaches (categories M2 and M3). They cover the safety and environmental elements of the construction – ranging from brakes and emissions to seat belts and the interior construction. The Framework Directive already applies ECWVTA to cars (category M1) and is currently being completely revised by the EC in order to require ECWVTA in all member states for larger passenger carrying vehicles, goods vehicles and trailers. Although no formal proposal has yet emerged, it is expected that ECWVTA will apply on an optional basis to M2 and M3 vehicles from around 2006 and will become mandatory for vehicles built and approved in a single-stage from around 2008 and to multi-stage built vehicles from around 2010.

ECWVTA is primarily aimed at vehicles produced in large numbers which are of identical design. However when it becomes a requirement in the UK, there will still be scope for simplified national approval schemes for 'small-series' vehicles (likely to be limited to a maximum of 250 vehicles of each 'type' in each Member State) and 'single approvals' for vehicles which will only be used here and not intended to be sold or used in other Member States. It is anticipated that new vehicles to be employed using clean fuel technologies are likely to conform to ECWVTA regulations, but full consultation should be undertaken with potential manufacturers to ensure that this is the case.

The Traffic Commissioners, who licence bus operators and keep the register of local services, can in special cases impose 'traffic regulation conditions' on operators of local buses in particular places, to prevent danger or reduce severe traffic congestion. The conditions that can be imposed relate to routes, stopping places and numbers of vehicles. DfT are currently consulting on allowing the Traffic Commissioners additionally to impose conditions regarding the emissions standards of vehicles as a more direct way of limiting air pollution.

## Legislation relevant to Competition

The Competition Act 1998 came into full effect from 1 March 2000. This Act has a particular bearing on the bus industry. The Act specifically prohibits agreements between undertakings, decisions by associations of undertakings or concerted practices which have the object or effect of preventing, restricting or distorting competition in the UK and conduct by one or more undertakings which amounts to the abuse of a dominant position in a UK market. The Act defines the limits of anti-competitive actions that may be undertaken by bus and transit operators. Traditionally the DTI has taken a relatively tough line in applying such legislation in areas such as timetabling and ticketing.
The Transport Act 2000 lays out arrangements for local authorities to take responsibility for developing integrated ticketing schemes which go beyond those allowed by the Competition Act.

# Appendix 4: Cleaner Bus Working Group Members

The Clear Zones Cleaner Bus Working Group members (as at July 2003) are:

| | |
|---|---|
| David Martin | Ecofys UK and Clear Zones Co-ordinating Team |
| Neil Smith | Transport & Travel Research and Clear Zones Co-ordinating Team |
| Anna Rickard | Energy Saving Trust |
| John Bridgman | Department for Transport |
| Andy Wren | Hampshire County Council |
| Adrian Wickens | Volvo Bus Ltd |
| Mike Chapman | LPG Association |
| Colin Copelin | Confederation of Passenger Transport |
| Keith Taylor | Newcastle City Council |
| Cliff Dallinger | Merseytravel |
| Myles Mackie | Coventry City Council |
| Maurice Perl | Wrightbus Ltd |
| Rayner Meyer | Sciotech |
| Roy James | Chive Fuels |
| Malcolm Pratt | Powertorque Engineering Ltd |
| Martin Pemberton | Transport Design International |
| Justin Ram | Department for Transport |
| Nick Harbord | CJ Jones (Keygas) Ltd |
| Henry Clayton | Shell Gas |
| Fred Parker | Natural Gas Vehicle Association |

This report was authored by David Martin and Neil Smith.

The views expressed in the report do not necessarily reflect the views or policies of individuals or organisations represented on the Working Group.

transport**energy**

# The Route to Cleaner Buses

## A guide to operating cleaner, low carbon buses