The Report of the Alternative Fuels Group of the Cleaner Vehicles Task Force

An assessment of the Emissions Performance of Alternative and Conventional Fuels

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Abbreviations used in this document

ACEA	Association des Constructeurs Europeen d'Automobiles
AFC	Alkaline Fuel Cell
AFV	Alternatively Fuelled Vehicle
BEV	Battery Electric Vehicle
BPEV	Battery Powered Electric Vehicle
CARB	California Air Resources Board
CNG	Compressed Natural Ga
CO	Carbon monoxide
CO_2	Carbon dioxide
DETR	Department of the Environment, Transport and the Regions
DTI	Department of Trade and Industry
DVLA	Driving Vehicle Licence Agency
EC	European Commission
EGR	Exhaust Gas Recirculation
HDV	Heavy Duty Vehicle
EU	European Union
ENGVA	European Natural Gas Vehicle Association
EST	Energy Saving Trust
ETC	European Test Cycle
ETSU	Energy & Technology Support Unit
EV	Electric Vehicle
EVP	Electric Vehicle Progress
FCEV	Fuel Cell Electric Vehicle
GDI	Gasoline Direct Injection
GHG	Greenhouse Gas
GWP	Global Warming Potential
HC	Hydrocarbons
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
LDV	Light Duty Vehicle

LEAF	Lifetime Evaluation of Alternative Fuels
LGV	Light Goods Vehicle (Van<3500kg)
LHICEV	Liquid Hydrogen Internal Combustion Engined Vehicles
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LPGA	Liquefied Petroleum Gas Association
MIRA	Motor Industry Research Association
Ni-Cd	Nickel-Cadmium Battery
Ni-MH	Nickel Metal-Hydride Battery
NGV	Natural Gas Vehicle
NGVA	Natural Gas Vehicle Association
NOx	Nitrogen oxides (excluding nitrous oxide)
NSCA	National Society for Clean Air
OBD	On-Board Diagnostic
OEM	Original Equipment Manufacturer
PEM	Proton Exchange Membrane
PM	Particulate Matter
ppm	parts per million
RM	Royal Mail
RME	Rape Methyl Ester
SULEV	Super Low Emission Vehicle
THC	Total Hydrocarbons
ULEV	Ultra Low Emission Vehicle
USABC	United States Advanced Battery Consortium
VOC	Volatile Organic Compound
ZEV	Zero Emission Vehicle

Introduction to the Report

The report addresses the objectives of the Alternative Fuels Group which are to consider:

- The merits and long-term potential for introducing alternative fuels and technologies.
- The barriers and mechanisms for introducing alternative fuels into the marketplace.
- Infrastructure issues and mechanisms for developing improved infrastructure to make alternative fuels more widely available.

This report details the findings and recommendations of the Alternative Fuels Group of the Cleaner Vehicles Task Force. The report investigates the potential environmental benefits associated with the use of alternative road fuels and technologies, the change in capital and operational costs, the required new infrastructure and the non-fiscal barriers which may affect market introduction. The cost-effectiveness of each of the options is also considered.

The content of the report is the result of a series of meetings of the Alternative Fuels Group held between July 1998 and December 1999. The members of the group represent the oil industry, motor vehicle manufacturers, fuel suppliers, transport executives and other associations which have an interest in road transport issues. Members of the Group, and those who have contributed to the work of the Group, are as follows:

Jonathan Murray	Energy Saving Trust, chairman
Meg Annesley	Association of UK Oil Independents (AUKOI)
Andrew Armstrong	BP Amoco Group
John Baker	EA Technology
Katherine Bennett	Vauxhall Motors Ltd.
Tim Brown	National Society for Clean Air
Geoff Callow	Motor Industry Research Association
Henry Clayton	Shell Gas
Geoff Day	Freight Transport Association (FTA)
Tom Fidell	Liquefied Petroleum Gas Association
Rupert Furness	Department of the Environment and Transport and the Regions
Mark Gaynor	Department of the Environment and Transport and the Regions
David Hart	Imperial College
Philip Heseltine	Merseytravel
John Hollis	Rover Group
Stuart Kirkham	EA Technology
Ben Lane	Ecolane Transport Consultancy
Ken Lillie	Energy Technology Services

Alistair Livesey	Shell Global Solutions
John Lucas	Association of UK Oil Independents (AUKOI)
Colin Macrae	Greenergy UK Ltd.
Joshua McCallum	Department of the Environment and Transport and the Regions
Malcolm Noyle	Vauxhall Motors Ltd.
Fred Parker	Natural Gas Vehicle Association
Leith Penny	City of Westminster
Keith Reed	Royal Mail
Ashley Roberts	Department of Trade and Industry
Jon Singer	Society of Motor Manufacturers and Traders
Paul Sterlini	Electricity Association
Malcolm Watson	UK Petroleum Industry Association
Matthew Whitehead	Ford Motor Company
Kerry Vitalis	Department of Trade and Industry

A wide range of alternative fuels and vehicle technologies have been considered by the Group and compared with conventional road fuels. The comparisons have been made on the bases of both emissions benefits and costs. The Group actively sourced the latest quantitative and qualitative data available on the use of alternative fuels and technologies in both the UK and in other countries.

Current representative emissions and cost data have been obtained from a wide range of sources. Data was sourced from members of the Group, and from reputable UK/European test centres. Interviews with experts in the field were conducted to confirm information provided and to ascertain the most likely future development of the options discussed.

Information on the operational experience of using alternative fuels was collected. This provided evidence of how alternative fuels and technologies perform in real-world conditions. This was collected from Group members and from published European and UK reports. The Group was particularly interested in identifying technical, fiscal and social barriers which can inhibit the introduction of the alternative fuels and technologies.

The Department of Environment, Transport and the Regions (DETR) developed a cost-effectiveness model to evaluate the data collected. This combined the sourced emission and cost information to provide a measure of the cost-effectiveness of each fuel-technology optionin reducing regulated and CO_2 emissions (on a lifetime-grams per pound spent basis).

The process of data collection, analysis and discussion led the Alternative Fuels Group to identify the potential for emissions benefits and the cost implications of each option considered and to arrive at conclusions regarding the most cost-effective applications of the fuels and technologies concerned. This resulted in a series of recommendations on which alternative fuels and technologies should be encouraged for use within the UK both in the shorter and longer term.

The Report is structured into six Sections. The first consists of **an Introduction**, an **Executive Summary** and the **Recommendations** of the Alternative Fuels Group. These parts summarise all the findings of the Group.

Section A outlines the overall impact of road vehicle emissions on the environment. It then briefly describes the conventional and alternative fuels and technology options which are available now or by 2005.

Section B focuses on seven fuel-technology options which are considered by the Group to have potential for being cost-effective in reducing vehicle emissions over the next 5 years. For each option, technical, infrastructural, operational, environmental and economic issues are discussed.

In **Section C**, the options are compared on an emission and cost basis. Using the Lifetime Evaluation of Alternative Fuels (LEAF) model developed by the DETR, the cost-effectiveness of each option is compared for a number of gaseous emissions. The results of the LEAF analysis are used with other information contained within the Report to form the recommendations of the Alternative Fuels Group. This section also describes the technical, economic and social barriers which currently inhibit the market introduction of each option.

Section D is a compilation of twelve case-studies and provides information on the real-world experience of fuel-technology options considered by the Report.

Section E contains tables and quantitative data which are drawn on throughout the report.

Notes on Terminology and Presentation of Data

The report bases its findings and analysis on emissions which are associated with road transport. These are the regulated *vehicle emissions* (carbon monoxide, particulate matter – PM_{10}, nitrogen oxides, total hydrocarbons) and *life-cycle emissions* of carbon dioxide and methane where relevant.

The term 'particulates' is used within the report to refer to PM_{10} (particles up to 10 microns in diameter). Concern about particulate matter has been focussed until recently on this size, of particle and the total mass of these particles was thought to be the crucial measurement. However, new research suggests that there may be significant health risks associated with much smaller particles in the 50–100 nanometres range. These particles are associated with petrol as well as diesel operation. Although in the future, considerations of the effect these particles from transport sources may be required, this report is based on available emission data which is largely restricted to PM_{10}.

Other pollutants (such as sulphur dioxide) have not been included since the emissions of these pollutants from road transport are relatively small compared to other sources of the pollutant.

For all vehicle fuels and technologies considered by this report, data for vehicle fuel economy, regulated vehicle emissions and associated costs is presented in absolute values wherever possible. In addition, lifecycle CO_2 and methane emission data is calculated using vehicle emissions and accepted assumptions regarding production emission of these greenhouse gases. Emission and cost data is taken from a number of sources and is summarised in Section C with emission tables showing main vehicle data in Section E.

Note that for some zero-emission vehicles, the emissions associated with electricity production have been excluded from the analysis and only CO_2 and methane are considered. This is to simplify the comparison of vehicle fuels and technologies. Thus some of the findings which relate to the regulated emissions for battery and fuel cell electric vehicles are best applied to urban areas away from electricity or hydrogen generating stations where the full benefits of zero emission vehicles will be realised.

Charts B2–B41 which relate to emission and cost data and Charts C1–C48 which relate to the cost-effectiveness analysis, show a range of values with a central datum point and upper and lower limits. The 'median' datum is taken from an actual measurement. These values are shown in the Tables E1-E5. The data sourced is intended to provide high quality back-to-back comparisons and may not always represent the most up-to-date fuel/technology currently available. The upper and lower limits are taken, where possible, from the Powershift registers and the VCA handbook and therefore represent a large number of tested vehicles. The limits provide the most reliable method of comparison. The 'median' provides test data from an actual vehicle, tested under known conditions.

Where quantitative data is presented, these are shown as absolute values in units of g/km for passenger cars and light duty vans and heavy-duty vehicles. The Euro Standards 2, 3 and 4 are referred to throughout the report and the limits are set out in Section E. For heavy-duty vehicle, the analysis is conducted in g/km whereas the limits are specified in g/kWh. Quoted, costs are in Pounds Sterling or pence and the other units are quoted in metric units where possible.

Executive Summary

This report details the findings of the Alternative Fuels Group of the Cleaner Vehicles Task Force. The report addresses the objectives of the Group which are to consider:

- The merits and long-term potential for introducing alternative fuels and technologies.
- The barriers and mechanisms for introducing alternative fuels into the marketplace.
- Infrastructure issues and mechanisms for developing improved infrastructure to make alternative fuels more widely available.

This report investigates the potential benefits associated with the use of alternative road fuels and technologies, the change in capital and operational costs, the required new infrastructure and the fiscal and non-fiscal barriers which may affect market introduction. In addition, the cost-effectiveness of each of the options is considered.

For the purposes of the report, an 'alternative fuel' is defined as one which could be used to partially or fully replace conventional petrol and mineral diesel fuels which also offers potential air quality or climate change benefits. An 'alternative vehicle' technology is one which could partially or fully replaces conventional vehicle systems and which can fully realise the potential for the emission reductions offered by the use of cleaner fuels.

The alternatives considered include cleaner conventional fuels, gaseous fuels and vehicles which utilise electric drive-trains (battery, hybrid or fuel cell electric). Using the resources of the expert panel who form the Alternative Fuels Group and current emission and cost data, the report recommends the use and development of particular fuels and technologies which both offer emissions benefits and have the potential to be commercially viable. The report also recommends measures to hasten their market introduction.

The Alternative Fuels Group makes its recommendations using two fuels and vehicle technologies as baselines with which alternative fuels and vehicle types are compared. These baselines are unleaded petrol and ultra low sulphur diesel (<50 ppm sulphur) which are used within production standard petrol and diesel internal combustion technology. Vehicle technologies are assumed to conform to the Euro 3 Standards from 2000 and Euro 4 from 2005 (see Appendix E).

The analysis has been conducted for five basic vehicle types which are representative of the majority of road vehicles currently in use. These are the Passenger Car or Car Derived Van (1500–1800 cc), the Panel Van (<3.5 tonnes GVW), the Single Deck Bus (12m, 44 seat), the Rigid Truck (17 tonne GVW) and the Articulated Truck (38/40 tonnes GVW). For passenger cars and light vans the performance has been compared to petrol driven vehicles, whilst for the Heavy Duty Vehicles, Ultra Low Sulphur Diesel (ULSD) is used the baseline.

The report bases its findings and analysis on six emissions which are associated with road transport. These are the regulated *vehicle emissions* (carbon monoxide, particulate matter – PM_{10}, nitrogen oxides, total hydrocarbons) and *life-cycle emissions* of carbon dioxide and methane.

Environmental Benefits

The Alternative Fuels Group considers that the following alternative fuels and technologies offer the potential for air quality, noise and climate change benefits and have the potential to be commercially viable in the short, medium or long-term:

- cleaner petrol (<50 ppm sulphur);
- cleaner diesel (<50 ppm sulphur) used in conjunction with exhaust after-treatment;
- natural gas (NG);
- liquefied petroleum gas (LPG);
- battery electric vehicles (BEV);
- hybrid electric vehicles (HEV);
- fuel cell electric vehicles (FCV).

The Group note that, for some of the alternatives considered, the potential for emission reductions may be reduced in comparison with conventional vehicle systems due to the improvement of conventional fuels and vehicle technology. For example, the use of low sulphur petrol will be mandated by European legislation in 2005, and will therefore become the 'conventional' baseline petrol fuel used. Moreover, all petrol and diesel ICE vehicle will have to conform to the Euro 4 vehicle emission standards which come into effect in 2005 (see Annex E).

Assuming the improvement in conventional vehicle fuels and technologies continues, the Group considers that it is unlikely that any one of the alternative fuels considered will replace petrol and diesel fuels which will remain dominant into the Twenty-first century. However, for particular applications, and in sensitive areas, the use of alternative fuels and vehicles may become an increasingly important in reducing road transport emissions.

The potential benefits of alternative fuels can not be considered without their associated vehicle technologies. The analysis has therefore focused on the most promising fuel-vehicle type combinations.

Table A1: Fuel-Vehicle Technology Combinations Considered in Detail within Report

Fuel/Technology	Car/CD-Van	Panel Van	Bus	Truck	Artic
Ordinary Petrol	✓	✓	–	–	–
Ultra Low Sulphur Diesel	✓	✓	✓ (1)	✓ (1)	✓ (1)
Cleaner Petrol	✓	✓	–	–	–
Natural Gas	✓ (2)	✓ (2)	✓ (3)	✓ (3)	✓ (3)
Liquefied Petroleum Gas	✓ (2)	✓ (2)	✓ (3)	–	–
Battery Electric	✓	–	✓	–	–
Hybrid Electric	✓ (4)	–	✓ (5)	–	–
Hydrogen ICE / Fuel Cell	✓	–	–	–	–

(1) with option for after-treatment technology (2) bi-fuel (3) dedicated (4) petrol-hybrid (5) diesel-hybrid

Following a detailed analysis of current emission data, the Group has quantified the potential emission reductions which can be achieved by the use of the alternative fuels and vehicles. This data is sourced from the VCA handbook, the Powershift register and from independent, vehicle tests which enable comparison of the relative emissions of different fuel-vehicle combinations. The data used for the report is shown in tables E1 to E5 and in the Charts B2–B41 (independent test results plus upper and lower limits provided by VCA and Powershift). For a summary of the relative emission benefits associated with the options considered by the report, see Table A2.

Economic Issues

Although alternative fuels and vehicles offer the potential for emission reductions and performance improvements in some cases, the Group note that the cleaner fuels and technologies considered are currently associated with increased lifetime costs compared to conventional baselines. For some of the alternatives, higher capital costs may be in part, balanced by lower operating costs. The percentage public life-time cost comparisons are summarised in Table A3. For a full costing analysis, see Charts B2–B41 which show the total private and public life-time costs associated with each option.

Table A2: Typical Current % Emission Reductions of Cleaner Fuels/Technologies Considered
(Note : Table only intended as initial guide – for detailed emissions comparison see Charts B2-B41)

	Fuel	CO	THC	NOx	PMs	GHGs(1)
Light Duty Vehicles Petrol Baseline	Cleaner Petrol	o	o	-5–15%	N/A	o
	LPG (bi-fuelled)	-50–100%	-15–50%	-50–100%	N/A	-15–50%
	CNG (bi-fuelled)	-50–100%	+50–100%(3)	-50–100%	N/A	-15–50%
	Battery Electric	-100%	-100%	-100%	N/A	-50–100%
	Petrol Hybrid Electric	-50–100%	-15–50%	-50–100%	N/A	-50–100%
	Fuel Cell Electric (2)	-100%	-100%	-100%	N/A	-50–100%
Light Duty Vehicles ULSD Baseline	LPG (bi-fuelled)	-15–50%	-5–15%	-50–100%	-50–100%	+5–15%
	CNG (bi-fuelled)	-15–50%	+50–100%(3)	-50–100%	-50–100%	+5–15%
	Battery Electric	-100%	-100%	-100%	-100%	-15–50%
	Fuel Cell Electric (2)	-100%	-100%	-100%	-100%	-15–50%
Heavy Duty Vehicles ULSD Baseline	ULSD + CRT	-50–100%	-50–100%	-5–15%	-50–100%	o
	LPG (dedicated)	-50–100%	-50–100%	-50–100%	-50–100%	o
	CNG (dedicated)	-50–100%	+50–100%(3)	-50–100%	-50–100%	+0–15%
	Battery Electric	-100%	-100%	-100%	-100%	-15–50%
	Diesel Hybrid Electric	+15–50%	-50–100%	-15–50%	-15–50%	-15–50%

Notes: (1) GHGs – Greenhouse gases included in analysis are CO_2 and CH_4

(2) Hydrogen fuel used (3) can be greater than 100% increase in total hydrocarbons

(3) can be greater than 100% increase in hydrocarbons

Key: (o) no significant reduction/increase – typically <5% change

(-100%) indicates 100% reduction compared to baseline of zero-emissions

- indicates a reduction, + indicates an increase

Table A3: Changes in Total Life-time (Public) Costs†
(Note: Table only intended as initial guide – for detailed cost comparison see Charts B2-B41)

	Fuel	Car/CD-Van	Panel Van	Bus	Truck	Artic
Baselines	Ordinary Petrol	✓	–	–	–	–
	Ultra Low Sulphur Diesel	–	✓	✓	✓	✓
Cleaner Fuels	Cleaner Petrol	o	–	–	–	–
	ULSD+CRT	–	–	+0–15%	+0–15%	(2)
	Natural Gas	+15–50%	+15–50%	+15–50%	+15–50%/ +50–100%	+15–50%/ +50–100%
	Liquefied Petroleum Gas	+15–50%	+15–50%	+15–50%	–	–
	Battery Electric	+50–100%	–	+50–100%	–	–
	Hybrid Electric	+15–50%	–	+50–100%	–	–
	Fuel Cell Electric (1)	+50–100%(3)	–	–	–	–

Notes: (1) Hydrogen fuel used (2) further work required (3) significantly greater than 100% increase

Key: (o) no significant reduction/increase – typically <5% change

† See Section C for definition of Public Costs

- indicates a reduction, + indicates an increase

Cost-Effectiveness Analysis

The analysis conducted by DETR included a cost-effectiveness comparison of reducing PM_{10}, NO_x and CO_2 emissions for each of the options considered. The cost-effectiveness ranking in this report only covers the options considered. There may be other technical or non technical measures outside the scope of this report that are more cost effective at reducing vehicle emissions (see Section C for cost-effectiveness values).

The cost-effectiveness analysis, led to the following conclusions:

FOR LIGHT-DUTY VEHICLES (PETROL BASELINE)

- Cleaner petrol is highly cost-effective in reducing NO_x (shown for LGVs only).
- CNG, LPG, BEV and P-HEV all show a moderate cost-effectiveness for NO_x reduction. The level of reduction of NO_x is larger for electric drive-trains.
- CNG, LPG, BEV and P-HEV all show moderate cost-effectiveness for CO_2 reduction with BEVs being slightly lower than the other options. The level of reduction of CO_2 is larger for electric drive-trains.
- CNG, LPG, BEV and P-HEV are all low in particulates.
- The cost-effectiveness of P-HEV for reducing NO_x and CO_2 (highest cost-effectiveness for both) will increase in the future.

FOR LIGHT-DUTY VEHICLES (ULSD BASELINE)

- CNG and LPG are both moderately to highly cost-effective for NO_x reduction (LPG is highest) and moderately cost-effective for PM_{10} reduction (LPG is highest).
- BEV and P-HEV both show a low to moderate cost-effectiveness for NOx (BEV is highest) and a low to moderate cost-effectiveness for PM_{10} (P-HEV is higher).
- BEV and P-HEV are both moderately cost-effective in CO_2 reduction (P-HEV is the highest).
- In the future gaseous fuels will continue to be cost-effective for reducing NO_x and PM_{10} and the electric drive train options will continue to be cost-effective for reducing CO_2.

FOR HEAVY-DUTY VEHICLES (ULSD BASELINE)

- ULSD+CRT are moderately cost-effective in reducing NO_x and have highest cost-effectiveness for PM_{10} reduction. However, in some cases for the NO_x reduction, is relatively small.
- CNG and LPG are both moderately cost-effective in reducing NO_x.
- BEV is moderately cost-effective in reducing NO_x and most cost-effective for CO_2 reduction.
- D-HEV is moderately cost-effective for reducing NO_x and highly cost-effective for CO_2 reduction.
- D-HEV will become increasingly cost-effective in reducing NO_x, PM_{10} and CO_2. In the future, for buses, D-HEV is predicted to be the most cost-effective option for reducing NO_x and CO_2.
- Future trends indicate that gaseous fuels will become less cost-effective in reducing NO_x, and BEVs will become less cost-effective in reducing CO_2.

RECOMMENDATIONS BASED ON COST-EFFECTIVENESS

The conclusions from the cost-effectiveness analysis were used in conjunction with the data in Section B to support the following recommendations on the use of alternative fuels and vehicle technologies:

- For light-duty vehicles, gaseous fuels (NG and LPG) should continue to be encouraged on the basis of their moderate cost-effectiveness in reducing NO_x, PM_{10} (compared to diesel) and CO_2 (compared to petrol). For heavy-duty vehicles, gaseous fuels should continue to be encouraged on the basis of their moderate cost-effectiveness in reducing NO_x.
- For heavy duty diesel vehicles, the introduction of after-treatment systems (such as CRT) should be encouraged on the basis of the high cost-effectiveness of this option in reducing PM_{10} and NO_x. This implies the use of ultra low sulphur diesel (<50 ppm) which will be mandatory in Europe from 2005 and is already used in the UK.
- For light duty vehicles, battery electric vehicles (BEVs) should be supported on the basis of their moderate cost-effectiveness in reducing urban NO_x and lifecycle CO_2 and a low to moderate cost-effectiveness in reducing urban PM_{10} (compared to diesel baseline). Battery electric buses should be supported on the basis of their at least moderate cost-effectiveness in reducing urban NO_x and lifecycle CO_2.

- For light duty vehicles, petrol hybrid electric vehicles (P-HEVs) should be supported on the basis of their current moderate cost-effectiveness in reducing CO_2, NO_x (compared to petrol) and a low to moderate cost-effectiveness in reducing PM_{10} (compared to diesel). Diesel hybrid electric buses should be supported on the basis of their moderate and high cost-effectiveness in reducing NOx and CO_2 respectively. In addition, future trends for D-HEVs suggest a significant improvement in cost-effectiveness for reducing NO_x, PM_{10} and CO_2. In the future, diesel hybrid-electric buses are predicted to be the most cost-effective option for reducing NO_x and CO_2.

- Fuel cell vehicles offer the promise of zero or very low vehicle emissions, with performance and range equal or better than conventional vehicles. However, at present they are not a cost-effective option. Costs associated with production will have to be significantly reduced and issues related to fuel infrastructure will have to be solved before this technology can be a cost-effective solution to reducing local and global emissions.

Market Acceptance

Vehicle purchasers may be reluctant to pay the additional costs currently associated with alternative fuels and technologies. Therefore, the Group is of the opinion that on-going market incentives will be significant in determining the market introduction of alternative fuels and vehicle technologies.

The market for alternative fuels and technologies will be strongly influenced by one or more of the fowllowing:

- Consumers' and operators' perception of costs which may be different to 'actual' costs.

- Predicted cost benefits to the customer/operator, such as improved fuel economy and reduced fuel costs.

- Customer/operator beneficial performance features, such as drive quietness and smoothness.

- Other savings in vehicle cost/complexity to the manufacturer, especially in the areas of emission control equipment and exhaust after-treatment.

- Possible vehicle access restrictions to city centres for all but low-emission vehicles.

- Increasingly stringent European legislation which may favour alternative fuels and technologies.

In addition to the cost implications associated with the introduction of cleaner vehicle types, the Group is of the opinion that the required development and implementation of a new fuel infrastructure poses a major barrier to the introduction of some cleaner fuels. This is especially true for natural gas and liquefied petroleum gas vehicles.

Therefore the introduction of cleaner vehicles could depend upon one or more of the following:

- The conversion of refining plants to produce cleaner petrol and diesel.
- A dependable and secure supply of cleaner fuels of high and consistent quality.
- The development of an adequate network of depot based refuelling points for fleet use.
- The development of an adequate network of publicly accessible, easy-to-use refuelling points on existing and new forecourt sites.

There is often a reluctance for individuals, transport operators, manufacturers and suppliers to fully appreciate the advantages of new technologies and the Government support available. Therefore, the Group notes that information and knowledge barriers can significantly hinder the adoption of new transport technologies.

The introduction of cleaner vehicles will depend upon addressing one of more of the following factors:

- A low knowledge base regarding the potential benefits of cleaner fuels and vehicles.
- A low knowledge base regarding the market start-up barriers for cleaner fuels and vehicles.
- Planning restrictions based on a poor understanding of safety hazards of cleaner fuels.
- A resistance to change transport behaviour among vehicle users.
- Lack of consumer confidence in performance and image of some cleaner vehicles.
- Perceptions of safety associated with cleaner vehicles.

Barriers to the introduction of cleaner diesel

The main barriers which affect the introduction of **cleaner conventional fuels** are:

- Cleaner diesel complying with existing BSEN 590 and ULSD requirements can give higher fuel consumption than standard diesel complying with BS EN 590.
- As of the end of 1999, supplies of cleaner petrol (<50 ppm) grades are restricted. Currently, there are no fiscal incentives to encourage production and use of this fuel before 2005. All the parties concerned have to agree to the switch, hence the need for a large incentive and a lead time. Investment in refining capacity and distribution agreements amongst fuel suppliers is required.

- According to the motor industry, in the longer term, fuels with sulphur levels below 50 ppm may be required to enable the use of after-treatment systems operating at high efficiency (not proven in this report). There is no Europe-wide consensus or incentive at present to encourage the uptake of petrol and diesel fuels with <10 ppm sulphur content.

Barriers to the introduction of gas vehicles

The main barriers which affect the introduction of **liquefied petroleum gas (LPG) and natural gas (NG) vehicles** are:

- the high capital cost of LPG and NG vehicles for certain market sectors.
- the low demand for gas fuelled vehicles. At present the principal customers for gas fuelled vehicles are in the public sector. The move to the private sector will be encouraged when a large part of the motoring public see that these refuelling stations are readily available in their locality.
- the vehicle weight penalty imposed by CNG storage tanks which reduces the payload. Dedicated CNG vehicles can have a limited range due to gas storage limitations. LNG vehicles have a good range but need a more complicated fuel infrastructure.
- the emissions certification for light-duty vehicles. This is currently based on total hydrocarbons, which gives an unfair reflection of ozone forming potential. For natural gas this should be based on separate standards for methane and non-methane hydrocarbons.
- the requirement for OBD systems to be fitted to gaseous (and petrol) fuelled vehicles from 1st Jan 2000 (a delay in introduction has been allowed for diesel vehicles until 2003). No OEM is able to develop this system for gaseous fuels in the timeframe required.

Barriers to the introduction of battery electric vehicles

The main barriers which affect the introduction of **battery electric vehicles (BEVs)** are:

- the high cost of these vehicles compared to conventional ICE vehicles, largely because they are not made in high volume, means that supply of BEVs is limited. However, the high purchase cost can be offset by lower cost of operation.
- the performance and vehicle range of BEVs is less than conventional vehicles.
- the lack of recharging stations.

- At present the principal customers for electric vehicles are in the public sector. The private sector will be encouraged when a large part of the motoring public see that recharging stations are readily available in their locality.

Barriers to the introduction of hybrid electric vehicles

The main barriers which affect the introduction of **hybrid electric vehicles** are:

- the high cost of hybrid electric vehicles compared to conventional ICE vehicles. This is due to development costs and because they are not yet made in high volume. However, this situation for HEVs is likely to change during the year 2000 when Toyota and Honda hybrid vehicles are launched commercially in Europe.

- the uncertainty about the optimum system design for hybrid electric vehicles (e.g. parallel versus series designs).

Barriers to hydrogen and fuel vehicles

The main barriers which affect the introduction of **hydrogen ICE and fuel cell electric vehicles (FCVs)** are:

- the current cost of fuel cell electric vehicles, which is much higher than conventional ICE vehicles. This is largely because of the high development costs and because they are not made in large volumes. This situation may change in 2003/4 when several major motor manufacturers plan to commercially launch fuel cell vehicles;

- the high degree of uncertainty concerning the optimum system design for fuel cell electric vehicles;

- the high uncertainty regarding the best fuel infrastructure for supplying hydrogen. The main contenders include pure hydrogen and reforming natural gas, methanol and synthesised low sulphur petrol.

Recommendations of the Alternative Fuels Group

Each recommendation is structured in three parts. These consist of a list of closely related *goals* which recommend a change or introduction of a fuel-technology combination for use within a particular vehicle sector, a *rationale* which explains the reasoning for the recommendation, and a *strategy* which identifies the mechanisms which can be used to implement the recommendation.

RECOMMENDATION 1

Continue to Improve the Performance of Cleaner Diesel

Goal	**1.1**	**To remove the remaining technical problems associated with the use of some ultra low sulphur diesel fuels.**
Rationale	1.1	ULSD (sulphur <50 ppm) provides significant emission benefits when compared to 'conventional' diesel (<500 ppm) and enables the use of some after-treatment systems which further reduce vehicle regulated emissions. Therefore, any problems associated with the fuel's use need to be addressed e.g. higher fuel consumption and operational problems in a small number of old heavy goods vehicles in hot weather.
Strategy	1.1	As a short-term measure to improve the performance characteristics of cleaner diesel, it is recommended that the maximum limit for density of ULSD as quoted in the 1998 Finance Act, should be increased from 835 kg/m^3 to 845 kg/m^3.
	1.2	As a long-term measure to improve the performance characteristics of cleaner diesel, changes should be made to BSEN 590 as follows: • Limits for aromatics should be quoted. • Any move to reduce the minimum density or viscosity should be resisted.

RECOMMENDATION 2

Continue to Encourage the Use and Introduction of Cleaner Conventional Fuels and Technologies

Goal	**2.1**	**To support the continuing use of ultra low sulphur diesel (<50 ppm sulphur) with exhaust after-treatment systems for all vehicle types and to consider the future reduction in sulphur levels to <10 ppm.**
	2.2	**To consider the introduction of ultra low sulphur petrol (<50 ppm) before 2005 with a view to future reduction to <10 ppm.**
Rationale	2.1	The introduction of after-treatment systems (such as CRT) should be encouraged on the basis of the high cost-effectiveness of this option in reducing PM_{10} and NOx for heavy-duty diesel vehicles. This requires the use of ultra low sulphur diesel (<50 ppm) which will be mandatory in Europe from 2005 and is already used in the UK. It is the contention of the motor industry that a further reduction of sulphur levels to <10 ppm would further assist the efficiency and longevity of after-treatment systems.
	2.2	Similar arguments for ULSD can be made on behalf of low sulphur petrol. A 50 ppm limit will come into force in 2005. It is the contention of the motor industry that a further reduction of sulphur levels to <10 ppm would further assist the efficiency and longevity of after-treatment systems and indirectly assist the introduction of technology to reduce fuel consumption (such as GDI).
	2.3	For light goods vehicles, cleaner petrol is highly cost-effective in reducing NO_x.
Strategy	2.1	The Government should review evidence from the motor and oil industry on the costs and life cycle benefits of cleaner petrol and diesel (<10ppm sulphur) as a matter of urgency. If persuaded of the cost-effectiveness of reducing sulphur in fuels, the Government should take the following actions.
	2.2	the Government should make representations to the EC for the adoption of a mandated fuel specification for cleaner petrol and diesel (<10ppm sulphur) across Europe.
	2.3	the Government should also consider unilateral action to encourage the early introduction of cleaner petrol (<50ppm sulphur) in advance of the introduction of a mandated fuel specification in 2005. This could be achieved by the Government introducing a 2 p/litre reduction of fuel duty on cleaner petrol.
	2.4	Fuel suppliers should develop plans to introduce further refining capacity to achieve the introduction of cleaner petrol (<50ppm sulphur) prior to 2005 and cleaner diesel (<10ppm sulphur) as soon as is technically possible.
	2.5	Vehicle and component manufacturers should fully demonstrate the potential emissions benefits achievable with extremely low sulphur level petrol (<50 ppm) and diesel (<10 ppm) to the UK Government and quantify the cost-effectiveness of these fuels.

RECOMMENDATION 3

Continue to Encourage the Use of Liquefied petroleum Gas (LPG) and Natural Gas (NG) Fuelled Vehicles in the Short to Medium Term

Goal	**3.1**	**To continue to promote the cost-effective introduction of liquefied petroleum gas (LPG) and natural gas (NG) vehicles in order to improve air quality in urban areas and assist in the reduction of greenhouse gas emissions from light-duty vehicles.**
	3.2	**To promote the development of a LPG and NG fuel infrastructure with national coverage which is accessible to the public.**
	3.3	**To encourage the use of dedicated engines for light-duty gaseous vehicles in parallel with fuel infrastructure development.**
Rationale	3.1	For light-duty vehicles, gaseous fuels (NG and LPG) should continue to be encouraged on the basis of their moderate cost-effectiveness in reducing NO_x, PM_{10} (compared to diesel) and CO_2 (compared to petrol). For heavy-duty vehicles, gaseous fuels (NG and LPG) should continue to be encouraged on the basis of their moderate cost-effectiveness in reducing NO_x.
	3.2	LPG and NG vehicles are also quieter than conventional vehicles.
Strategy	3.1	The Government should continue the financial assistance for LPG and NG vehicle purchase currently provided by the Powershift Programme at an appropriate level to stimulate market growth until the markets of these vehicles become self-sustaining. This should be reviewed by 2005 if not yet self sustaining.
	3.2	Fuel suppliers should continue to develop refuelling infrastructure for LPG and to seek to develop NG refuelling infrastructure which is not fleet specific but open to third parties.
	3.3	Powershift funding for the purchase/conversion of cleaner vehicles should be targeted at locations where publicly accessible NG and LPG refuelling infrastructure exists or is being introduced.
	3.4	The Government should provide local authorities with guidelines on how to assess planning applications for the installation of gaseous refuelling infrastructure.
	3.5	Vehicle and component manufacturers should demonstrate to Government the potential emissions benefits achievable with LPG and NG vehicles using dedicated engines and exhaust treatment equipment for gaseous fuels.
	3.6	The fuel duty on LPG and NG should be reduced to the EU recommended minimum of 8p/kg which should then remain in force until at least 2005. Furthermore, the Government should at least maintain the current duty differential between gaseous fuels and conventional road vehicle fuels which should then remain in force until at least 2005.
	3.7	The UK Government should encourage the emissions legislation within the EC to separate the total hydrocarbon limit for light-duty vehicles into a methane and non-methane standard as is already the case for heavy-duty engines.
	3.8	The date for the mandated use of on-board diagnostic (OBD) systems should be the same for gaseous fuelled vehicles as for diesel. The Government should lobby the EU to delay the introduction until 2003, the year that OBD systems will be mandatory for diesel.

RECOMMENDATION 4

Continue to Encourage the Use of Battery Electric Vehicles in Urban Niche Markets in the Short to Medium Term

Goal	**4.1**	**To encourage the cost-effective use of battery electric vehicles (BEVs) in urban areas and certain niche applications.**
Rationale	4.1	For the light-duty sector, battery electric vehicles should be supported on the basis of their moderate cost-effectiveness in reducing urban NO_x and life-cycle CO_2 and a low to moderate cost-effectiveness in reducing urban PM_{10} (compared to diesel baseline). Battery electric buses should be supported on the basis of their at least moderate cost-effectiveness in reducing urban NO_x and life-cycle CO_2.
	4.2	BEV's are 'zero' emission at point-of-use and are therefore excellent urban vehicles. The use of BEVs offers the possibility of zero lifecycle-emission transport if BEVs are recharged using renewably generated electricity.
	4.3	Due to range limitations inherent in BEVs, these vehicles are most suited for operations where the duty cycle is predictable, consistent and where daily range does not exceed 140 km per day and includes light-duty commercial and public transport applications.
Strategy	4.1	The Government should continue to financially assist vehicle purchase for battery electric vehicles, currently provided by the Powershift Programme at an appropriate level for market growth until the markets for these vehicles become self-sustaining. This should be reviewed by 2005 if not yet self sustaining.
	4.2	Vehicle manufacturers should seek to introduce BEVs for demonstration, testing. A larger range of models should be made commercially available in the UK at the earliest possible date.
	4.3	Local authorities and electricity suppliers should streamline the procedure for applying for planning permission to install recharging points. The specification and planning requirements used for the Capital Campaign for Cleaner Cars road-side charging post should be used as a model for future applications.
	4.4	Electricity supply companies should review the potential for providing cost-effective recharging facilities for electric vehicles in public locations.
	4.5	Local authorities should consider introducing free parking for battery electric (and other zero-emission) vehicles within urban centres. Parking space for zero-emission vehicles should be also promoted within new urban building developments and as part of employment urban parking schemes.
	4.6	There should be continued demonstrations of the practicability and benefits of BEVs, particularly where there are pressing operational and/or local air quality problems. These include inner urban postal and courier service use, targeted local authority applications, park and ride schemes, tourist shuttle bus operations and selected airport service vehicle operations.

RECOMMENDATION 5

Encourage the Introduction of Hybrid Electric Vehicles

Goal	**5.1**	**To encourage the cost-effective introduction of hybrid electric drive-train vehicles in order to reduce vehicle and life-cycle greenhouse gas emissions in the medium-term, specifically in the light-duty and bus sectors.**
Rationale	5.1	For the light duty sector, petrol hybrid electric vehicles (P-HEVs) should be supported on the basis of their current moderate cost-effectiveness in reducing CO_2, NO_x (compared to petrol) and a low to moderate cost-effectiveness in reducing PM_{10} (compared to diesel). Diesel hybrid electric buses should be supported on the basis of their moderate and high cost-effectiveness in reducing NO_x and CO_2 respectively. In addition, future trends for D-HEVs suggest a significant improvement in cost-effectiveness for reducing NO_x, PM_{10} and CO_2. Future diesel hybrid-electric buses (around 2005) are predicted to be the most cost-effective option for reducing NO_x and CO_2.
	5.2	Hybrid-electric vehicles provide very good vehicle and emission performance. Current passenger cars already conform to Euro 4 (year 2005) emission standards.
Strategy	5.1	The Government should continue the financial assistance for pre-commercial hybrid-electric demonstration projects as is currently provided by the Powershift Programme for as long as these technologies are considered to have a high future market potential.
	5.2	Once commercially available, the Government should financially assist vehicle purchase for hybrid electric vehicles, currently provided by the Powershift Programme at an appropriate level for market growth until the markets of these vehicles become self-sustaining. This should be reviewed by 2005 if not yet self sustaining.
	5.3	The Government and Industry should support a programme for independent monitoring of the development of these vehicles to continually assess their emission benefits, cost implications and market viability.
	5.4	Through the Foresight Vehicle Programme, the Government should continue to support the development of a UK component supplier base for hybrid-electric vehicles and systems.
	5.5	Vehicle manufacturers should seek to introduce hybrid-electric vehicles to be demonstrated, tested and made commercially available in the UK at the earliest possible date.

RECOMMENDATION 6

Encourage the Demonstration of Fuel Cell Electric Vehicles

Goal	**6.1**	**To continue to support pre-commercial fuel cell vehicle demonstration projects which enable the potential benefits of fuel cell technology to be assessed for possible use in the long term.**
Rationale	6.1	Fuel cell vehicles are 'zero' or ultra-low emission vehicles and are therefore excellent urban vehicles. The use of fuel cell vehicles offer the possibility zero-life-cycle emission transport if hydrogen is generated, compressed and distributed using renewable energy. Compared to conventional ICE vehicles, fuel cell vehicles are predicted to have comparable or improved range and performance.
Strategy	6.1	The Government should continue the financial assistance for pre-commercial fuel cell electric demonstration projects, currently provided by the Powershift Programme for as long as these technologies are considered to have a high future market potential.
	6.2	Once commercially available, the Government should financially assist vehicle purchase for fuel cell electric vehicles as is currently provided by the Powershift Programme at an appropriate level for market growth until the markets of these vehicles become self-sustaining. This should be reviewed by 2005 if not yet self sustaining.
	6.3	The Government and Industry should support a programme for independent monitoring of the development of these vehicles to continually assess their emission benefits, cost implications and market viability.
	6.4	Through the Foresight Vehicle Programme and the Advance Fuel Cell Programme, the Government should continue to support the development of a UK component supplier base for fuel cell electric vehicles and systems.
	6.5	Vehicle manufacturers should seek to introduce fuel cell vehicles to be demonstrated, tested and made commercially available in to the UK at the earliest possible date.
	6.6	The projected fall in the price of fuel cells needs to be monitored to ensure that the UK is prepared to take early advantage of fuel cell technology becoming commercially viable.
	6.7	Further work is required to determine the benefit of hydrogen ICE vehicles which have not been fully explored as part of this report. Hydrogen ICE vehicles could share the same refuelling infrastructure of hydrogen fuel cell electric vehicles.

RECOMMENDATION 7

Improve the Legislative and Fiscal Framework Relating to Cleaner Fuels and Vehicles

Goal	**7.1**	**To improve the legislative and fiscal framework relating to cleaner vehicles in order to further encourage the up-take of cleaner vehicles and to remove barriers which impede their introduction.**
Rationale	7.1	In some circumstances, the existing regulatory and fiscal environment which relates to fuel/vehicle construction and use can inhibit the introduction of cleaner vehicles. A considered change in some of the existing legislation would assist the up-take of cleaner vehicles.
Strategy	7.1	Government should use the structure of fuel duties for road transport fuels to support the objectives of the Climate Change policy and the Air Quality Strategy. Public awareness and continuity in the fuel duty structure will promote confidence amongst vehicle operators, fuel suppliers and vehicle manufacturers.
	7.2	Cleaner vehicles should continue to be encouraged through the use of reduced Vehicle Excise Duty (VED) incentives. This should be accompanied by clear labelling of the vehicle's emissions standards on the VED tax disc.
	7.3	The fuel duty rebate system should be reviewed. Currently the fuel duty rebate system reduces the incentive for Public Service Vehicle (PSV) operators to invest in cleaner vehicles.
	7.4	New mechanisms need to be found to encourage fleet operators of PSVs and taxis to invest in cleaner fuels and technologies.
	7.5	The Government should amend the existing UK Public Service Vehicles (Carrying Capacity) Regulations 1984 Regulations 6 2(a) to exclude a vehicle that has the floor of its passenger carrying area not more than 350 mm above the ground, and which has a maximum speed not exceeding 30mph. This would allow standees on vehicles with a seating capacity of less than 13 passengers, with low centre of mass and low maximum speed. Harmonisation of relevant vehicle construction and use legislation across the EC is also recommended.
	7.6	Powers should be available to local authorities to enter into binding quality contracts with bus and taxi operators which include minimum levels of environmental performance.
	7.7	Local authorities should consider the use of Low Emission Zones (and the implications for cleaner vehicles) when developing their statutory air-quality Action Plans (under the 1995 Environment Act).
	7.8	Local planning authorities should consider the availability of facilities for cleaner fuels within their areas, and include appropriate policies within their Unitary Development Plans to protect sites for cleaner fuel infrastructure development.
	7.9	Where suitable opportunities exist, local authorities should consider the desirability of entering into partnership with energy suppliers or other willing parties to offer alternative refuelling centres and street-side re-charging points in residential areas.
	7.10	When investing in alternative re-fuelling infrastructure, the vehicle operator should consider entering into a local partnership to encourage third party access to depot based re-fuelling facilities.
	7.11	Curfews times for delivery vehicles should be lifted for vehicles with demonstrable reduced noise.
	7.12	Government should consider regulatory measures to ensure converted gaseous fuelled vehicles meet current safety and environmental standards.

RECOMMENDATION 8

Improve the Access and Quality of Information Relating to Cleaner Fuels and Vehicles

Goal	**8.1**	**To improve the access and quality of information regarding cleaner fuels and vehicle technologies.**
Rationale	8.1	The technical and fiscal issues which surround the comparison of alternative and conventional fuels and technologies are complex. This is compounded by the lack of widely available, up-to-date information regarding cleaner vehicle emissions and costs. In addition, technologies are developing rapidly which means that information is quickly out-of-date.
Strategy	8.1	The Government should continue to support the development of the Powershift Register and other data sources which provide clear information on the environmental impact of cleaner vehicles for local authorities, fleet buyers and the general public.
	8.2	Government should identify and publicise examples of 'best practice' of cleaner vehicle use and introduction. Information should include policy guidelines for local authorities and passenger transport executives to encourage the up-take of cleaner vehicles. Potential sources of such policy recommendations are research being co-ordinated by the NSCA into Low Emission Zones and by the Energy Saving Trust through the Utopia Project.
	8.3	The Government in conjunction with vehicle manufacturers should continue to monitor cleaner vehicles to ascertain and confirm their environmental benefits and cost implications.
	8.4	Government, vehicle manufacturers and fuel suppliers should provide guidance to local authorities and other large fleet operators about the benefits and operational experience of cleaner vehicles and the purchase of suitable vehicles.
	8.5	The Government should conduct further work to recommend which road transport technology options are the most effective in helping to achieve UK air quality and climate change targets and to identify the cost implications of these options.
	8.6	The co-ordination of Government and industry views on cleaner vehicles should be continued through an appropriate forum.
	8.7	Leasing companies should consider mechanisms for publicising the sale of cleaner vehicles through a central register as a means of protecting residual values of cleaner vehicles.
	8.8	Government and local authorities should further demonstrate their commitment to cleaner vehicle solutions by leading the way in the purchase of cleaner vehicles. This would improve market confidence for cleaner vehicles.

SECTION A:

Cleaner Fuels and Cleaner Vehicle Technologies – Overview

The Impact of Road Vehicle Emissions on the Environment[1]

Most road vehicles burn hydrocarbon fuels using the internal combustion engine (ICE). This results in the production of gaseous emissions which are emitted during fuel production and road vehicle use. These emissions include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (THCs), particulate matter (PM_{10}) and indirectly, the formation of ground level ozone.

Vehicle emissions can have a harmful impact on local and regional air-quality and human health. Vehicles also emit 'greenhouse' gases such as CO_2 that are believed to affect the climate.

One of the most significant measures to reduce road transport related pollution has been the reduction in emissions from internal combustion engine vehicles through tighter standards on fuel and vehicle technology. New vehicles today emit less than 10% of all pollutants compared to pre-1970 models (NSCA, 1998).

The NO_x reductions required to meet higher emissions standards potentially had a high cost in terms of increased fuel consumption. In spite of this and the significant impact on fuel consumption which was necessary to achieve safety improvements and the demands of customers for additional on-board equipment, the average car fuel consumption reduced by 5% from 1970 to 1993, reducing CO_2 emissions per vehicle-km. (Potter, 1997). The ban on the sale of leaded petrol from January 2000 will further reduce air-borne lead emissions, which have already been substantially reduced by the introduction of lead-free petrol.

Although domestic and industrial sectors are also responsible for air pollution, road transport remains the predominant source for some emissions. This is the case for benzene (65%), 1,3-butadiene (77%), CO (75%) and NO_x (48%). Within urban areas, the percentage contributions due to road transport can be significantly higher. For example, although road transport is responsible for around 26% of PM_{10} on a national level, in

[1]A more detailed discussion of the environmental effects of road transport can be found in "Environmental Impacts of Road Vehicles in Use" published by the Cleaner Vehicles Task Force, July DETR, 1999.

London, road transport contributes 78% of known primary emissions of PM_{10}. Road transport is also a significant contributor of UK carbon dioxide (20%) and hydrocarbon emissions (30%) (DETR, 1999).

However, the expectation based on current policies is that the trend of declining emissions (for NO_x and PM_{10}) will slow down considerably from about 2010, come to a halt around 2020 and then slightly increase as engine and fuel improvements are offset by continuing traffic growth. Other emissions of local air pollutants are expected to follow a similar pattern. Carbon dioxide emissions from the road transport sector is projected to continue to increase over the coming decade to 36.5 MtC by 2010. Voluntary agreements with motor manufacturers to reduce CO_2 emissions from new cars are likely to reduce 2010 road transport emissions of CO_2 to 34.5 MtC (DETR, 1999).

MEASURES TO IMPROVE AIR QUALITY

In response to the growing scientific evidence and increasing public concern about the adverse effects of air pollution, the Government began in July 1997 to implement the National Air Quality Strategy. The Strategy aims to set a framework for improving air quality in the UK. It sets standards and objectives for eight major air pollutants and seeks to strike a balance between national and local action (see Table A4). The Strategy was reviewed in 1999 to take account of the latest scientific, economic and technical information and developments at European level. A revised Strategy has now been published.

Table A4: **Summary of UK National Air Quality Standards and Objectives**

Pollutant	level	unit	measuring period
Nitrogen Oxides	150/21	ppb	hourly/annual mean*
Carbon Monoxide	10	ppm	running 8 hour mean
Benzene	5	ppb	running annual mean
Partiulates (PM10)	50	µg/m3	running 24hr rolling mean*
Low-level Ozone	50	ppb	running 8 hour mean*
1,3-butadiene	1	ppb	running annual mean
Lead	0.5	µg/m3	annual mean
Sulphur dioxide	100	ppb	15 minute mean*

Notes: ppb – parts per billion, ppm – parts per million, *provisional initial targets.

Source: UK National Air Quality Strategy, Department of Environment, 1997.

The UK Government's assessment is that current and planned technology, regulatory measures and fiscal policies will result in the UK air quality objectives for CO, lead, benzene and 1,3 butadiene being met. However, it is expected that measures will be needed, particularly in urban areas to meet the objectives for NO_x and particulates.

In order to achieve all the UK Government's objectives to reduce the impact of road transport on the environment, several approaches are possible. These are clearly stated by the 1998 Integrated Transport White Paper and includes the need for "improvements in fuel and vehicle technology...[which] will make a significant contribution to achieving our targets for improving air quality and reducing greenhouse gases" (DETR, 1998c; para. 2.50). This approach includes:

- The introduction of cleaner fuels which reduce emissions on a per km basis.

- The introduction of cleaner, more efficient vehicle technologies through the:
  - incremental improvement of conventional vehicles;
  - addition of emission reduction technology;
  - introduction of cleaner vehicles.

Vehicle emissions can be reduced by improving fuel quality. Although, cleaner fuels have a smaller effect on emissions than new vehicle technologies, cleaner conventional fuels do offer the prospect of improving emissions from new and old vehicles alike whereas, in general, advances in vehicle technologies improve only new vehicles. As new vehicles make up only around 10% of the UK fleet, it can take several years to maximise the potential of technological improvements (NSCA, 1998). Ideally cleaner fuels need to be combined with the introduction of new vehicle technologies to maximise potential emissions reductions. In fact, the use of new technologies (e.g. exhaust after-treatment) is often dependent on the availability of cleaner products (e.g.s unleaded petrol and low sulphur fuels).

EUROPEAN FUEL AND VEHICLE EMISSION STANDARDS

The Auto-Oil programme was set up by the European Commission in 1993 to identify the most cost-effective means of improving air quality across Europe through improvements to vehicle technology and fuel specifications. It involved the Commission, the European oil and motor industries. This project informed the EU Directives known as Euro 1 and Euro 2, legislation which set mandatory limits for emissions of what are classed as 'regulated' emissions; carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC) and particulate matter less than 10 microns in size (PM_{10}).

Further recommendations from the Auto-Oil programme formed the basis of decisions made by the European Council of Ministers and Parliament in 1998. These set tighter limits for cars and light-duty vans (<3.5 GVW) came into effect on 1 January 2000 (Euro 3), with further, more stringent limits (Euro 4) coming into force in 2005. New limits have also been set for heavy-duty engines from 2001 (Euro 3), with more stringent limits being introduced in 2006/8 (Euro 4). The new standards for heavy duty engines require a more realistic 'transient test cycle' as opposed to a steady state test cycle.

In parallel with vehicle emission standards, European fuel directives require petrol and diesel fuels to meet a new, cleaner specification from 1 January 2000 and prohibits the general sale of leaded petrol from that date. More stringent standards will apply from 2005, mandating the use of ultra-low sulphur petrol and diesel. For petrol, maximum sulphur limits will be reduced from the current level of 500 ppm to 150 ppm in 2000 and 50 ppm in 2005, along with reductions in benzene from 5% to 1%. For diesel, the principal change will be a reduction in maximum sulphur levels to 350 in 2000 and 50 in 2005 (from a level of 500 in 1999). (See Annex F for details of the Euro 1, 2, 3 and 4 Vehicle Emission and Cleaner Fuel Standards.)

CARBON DIOXIDE EMISSIONS

The UK has a legally-binding greenhouse gas emission reduction target of 12.5% on 1990 levels by 2008–12 as part of the international response following the Kyoto Climate Change Convention in December 1997, together with a domestic target of reducing UK carbon dioxide emissions to 20% below 1990 levels by 2010. Although transport is responsible for approximately 20% of emissions of CO_2 (the main greenhouse gas), there is no current legislation which limits the amount of CO_2 produced by road vehicles.

The European Commission's Strategy on CO_2 from Cars aims to reduce emissions of CO_2 from new cars sold in the EU to an average of 120 grams per kilometre. This represents a cut of about a third on the current average. The Strategy, endorsed by the Council of Ministers in June 1996, seeks to achieve the target in large part through a voluntary commitment by European vehicle manufacturers, supplemented by fiscal measures and fuel economy labelling to influence consumer demand.

In July 1998, the Commission reached a formal agreement with ACEA, the European car manufacturers' representative, to implement the following for passenger cars:

- to bring to the market individual car models with CO_2 emissions of 120g/km or less by 2000;
- to an indicative intermediate target of 165–170g/km (average) in 2003 as the basis for monitoring progress;
- to reduce CO_2 emissions to an average of 140g/km by 2008 for all its new cars sold in the EU, a cut of about 25% on current levels;
- to review in that year the potential for additional improvements with a view to moving the new car fleet average further towards 120g/km by 2012;
- to get ACEA to co-operate with the Commission in the monitoring of the Commitment.

The implementation will be monitored jointly by the Commission and ACEA, and the Commission will report to the European Parliament and the Council of Ministers annually. Similar voluntary agreements have been agreed (in October 1999) between the Commission and Japanese and Korean motor manufacturers who have given a commitment to a fleet average for passenger cars of 140 gms/km by 2009.

Cleaner Fuels and Vehicle Technologies

There are two inter-related strategies for reducing the emissions from road transport to attain national and European, air quality and green-house gas targets:

- the introduction of cleaner fuels;
- the introduction of cleaner vehicles.

CLEANER FUELS

An alternative vehicle fuel is one which can be used to partially or fully to replace conventional petrol and mineral diesel fuels and which also offers *potential air quality or climate change benefits*. The main fuel contenders which have a potential to reduce emissions over the short, medium and longer terms are discussed below with references to the fuel's source and methods of utilisation.

Although some alternative fuels can be used within conventional ICEVs with significant changes to vehicle design, their use offers more potential for emission reductions if used within radically new propulsions systems, such as hybrid or pure-electric vehicles.

Cleaner Conventional Fuels – cleaner petrol and cleaner diesel

These are conventional fuels where the composition has been changed to reduce some gaseous emissions and increase efficiency of exhaust after-treatment systems. Typically, a cleaner petrol will have low sulphur, low benzene and may include oxygenates or blended alcohol (non- UK markets). Cleaner diesel will typically have low sulphur, reduced heavy hydrocarbons and a lower density than 'normal' diesel.

Gaseous Fuels – Compressed Natural Gas and Liquefied Petroleum Gas

Natural gas makes an ideal vehicle fuel for combustion engines because of its high octane rating and low VOCs. The natural gas used in the UK comes predominantly from North Sea oil and gas fields. Liquefied Petroleum Gas (arises in the extraction of natural gas and as a by-product of refining) also has characteristics which make it suitable as a cleaner vehicle fuel.

Biofuels – bio-diesel (RME), bio-ethanol, bio-methanol

These are produced by the crop-fermentation or esterification of seed-oil derivatives. In principle the use of biofuels is carbon neutral as all carbon released during their combustion has been absorbed by the feedstock crop as it grew. However, in practice energy is expended in growing, harvesting and refining biofuels, which means biofuels are not carbon neutral. Biofuels produced by fermentation process include alcohol fuels (bio-ethanol and bio-methanol). Esterification is used to process rape seed into Rape-seed Methyl Ester (RME), also known as bio-diesel.

Electricity – renewable and non-renewable

This is generated by the combustion of primary fossil-fuels, fission of nuclear fuels or is produced from renewable sources. Electricity is a secondary form of energy. If used within a 'pure' electric (battery powered) vehicle, it offers the possibility of a zero-emission vehicle (at point of use). Electricity generation generally produces gaseous pollutants. However, if renewable electricity is used, e.g. from wind or solar power, a vehicle could be operated with zero-emissions on a life-cycle basis.

Hydrogen – renewable and non-renewable

Like electricity, hydrogen is a secondary form of energy which can be derived from renewable and non-renewable sources. The advantage of using hydrogen is that it combusts within an ICE to form only water (plus some NO_x if burnt in air), since there is no carbon in the fuel. Hydrogen can also be used by a 'fuel cell' energy converter to produce electricity. This opens up the possibility of a new type of electric vehicle – the fuel cell electric vehicle (FCEV).

CLEANER VEHICLES

Although some alternative fuels can be used within conventional ICE vehicles without significant changes to vehicle design, they can offer greater emissions reductions if used in conjunction with new propulsions systems. Furthermore, the advent of cleaner fuels enables the use of advanced after-treatment systems which can further reduce the vehicle emissions.

Cleaner vehicles can be developed using two approaches. The first is to improve and develop the internal combustion engine through, for example, direct fuel injection, common rail, EGR and advanced diesel turbo. Examples of what can be achieved by the incremental approach, in California are the Honda Accord and the Nissan Sentra which have been certified by CARB as Super Low Emitting Vehicles (SULEVs) and will be on sale in the 2000 model year (AECC Newsletter Nov-Dec 1999.). Dedicated ICEs have also been developed which use alternative fuels such as alcohol, natural gas, liquefied petroleum gas and hydrogen.

The second approach is to develop part or complete alternatives to the ICE engine. This option includes battery powered EVs (pure-EVs) and other electric vehicle types such as 'series-' and 'parallel-hybrid' electrics and 'fuel cell' electric vehicles, which are described below.

The Battery Electric Vehicle (BEV)

Electricity from any energy source can be used to charge a rechargeable battery of electrochemical cells on-board a pure-electric vehicle. When required, electrical energy is drawn from the cells and converted to motive power by the use of an electric motor. Both a.c. and d.c. drive-train designs have been developed.

The Hybrid Electric Vehicle (HEV)

Series-hybrids are vehicles which use a heat engine (usually an ICE) to generate electricity which is then delivered to the wheels via electric motors. Parallel-hybrids can be powered mechanically or electrically, either by an ICE engine or by a battery motor system.

The Fuel Cell Electric Vehicle (FCEV)

If hydrogen 'fuel' and oxygen (from the air) are fed into a 'fuel cell', electricity is generated which can operate an electric motor. This can be used to power a fuel cell electric vehicle. A battery system can also be combined with a fuel cell to form a fuel cell-hybrid vehicle.

Fuel and Vehicle Technologies Considered by this Report

This document focuses on those alternative fuels and vehicles which are seen as providing air quality improvements and/or climate change benefits and have the potential to be commercially viable in the UK marketplace. Included for discussion are **cleaner petrol and diesel, natural gas** and **liquefied petroleum gas** which are regarded as having significant short-term potential in reducing vehicle emissions. Vehicles which use these fuels have the option of utilising exhaust after-treatment systems to further reduce emissions (e.g. catalyst and particulate trap technologies).

The use of **electricity** as a road fuel is also considered to be an important option for cutting road transport emissions. The last decade has seen several major demonstration projects throughout the world which have shown that **battery electric vehicles** are suited to certain niche applications; notably for urban use where drive cycles are predictable.

Another option is the use of **hybrid-electric vehicles**. Although these were to be considered a medium to long-term option in the early Nineties, in 1997, Toyota began to produce and sell a hybrid car the Prius. The vehicle sales have been very successful in Japan, and 1,500 cars are produced each month, although Toyota are reported to be incurring a loss on each vehicle. Toyota and Honda both plan to launch hybrid passenger cars in Europe by the end of the year 2000.

A promising longer term option is **hydrogen**. Used as a road fuel, hydrogen has been considered by many in the motor industry to offer great benefits for road transport; as it has provided for space exploration since the 1960s. Indeed, the more general hydrogen economy which could form the infrastructure for a fuel cell transport system has been considered by some to be "inevitable", providing a solution to the long term storage of renewable energy (Serfas et al., 1991). Vehicles could either use an internal combustion engine or fuel cell technology.

The alternatives considered by the remainder of this report are as follows:

Vehicles which utilise the Internal Combustion Engine (ICE) and use the following fuels:	• cleaner petrol (<50 ppm sulphur) • cleaner diesel (<50 ppm sulphur) used in conjunction with exhaust after-treatment • natural gas (compressed – CNG and liquefied – LNG) • liquefied petroleum gas (LPG) • hydrogen (H_2)
Vehicles which utilise electric drive trains	• battery electric vehicles (BEV) • fuel cell electric vehicles (FCV)
Vehicles which utilise the Internal Combustion Engine (ICE) and electric drive trains	• hybrid-electric vehicles (HEV)

FUELS NOT CONSIDERED BY THE REPORT

Three fuels often considered as alternatives to conventional fossil fuels for road transport are bio-diesel, bio-ethanol and bio-methanol. Derived as they are from energy crops, they are, *in principle*, CO_2 neutral. However, zero CO_2 life-cycle emissions are rarely the case when the energy used to grow, harvest and refine the bio-fuels are taken into account. Once these factors are taken into account, the life-cycle CO_2 emissions from energy crops are significant.

Furthermore, there are particular problems associated with land use in the UK, which means that it would not be possible for the UK to become self-sufficient in bio-fuel production. Therefore, although they may well have a contribution to make on a global scale with respect to vehicle emission reductions, these fuels are not included in this comparison of alternative fuels.

SECTION B:

Detailed Discussion of Cleaner Fuels/Technologies

Data Analysis and Presentation

In Section B, a summary is presented for each of the vehicle fuels and technologies considered by the report. Information relating to each option is structured as follows:

Summary	**General Concept** UK and European Experience
Vehicle	Vehicle Technology Vehicle Applications Vehicle Availability
Fuel	Fuel Characteristics Fuel Supply Infrastructure Issues
Environmental Issues	Vehicle Emissions Fuel Consumption & Life-cycle Emissions Safety Issues
Market Acceptance	Economic Issues Standards and Regulations Market Potential
Other Issues	Additional Comments

Cleaner Petrol

The advantages of cleaner petrol for automotive applications include:

- **slightly reduced regulated vehicle emissions;**
- **advantages are available to the majority of existing petrol vehicles;**
- **relatively simple introduction, using existing fuel infrastructure if it replaces another grade;**
- **increases to the efficiency of exhaust after-treatment catalysts.**

The current disadvantages associated with cleaner petrol include:

- **the low availability of fuel;**
- **increased cost.**

GENERAL CONCEPT

The EU Directive 98/70/EC mandated the introduction of cleaner petrol containing a maximum of 50 ppm sulphur, 35% aromatics and 1% benzene from 1 January 2005 with an intermediate quality containing a maximum of 150 ppm sulphur, 42% aromatics and 1% benzene from 1 January 2000. In other countries oxygenates have been added to petrol mainly to reduce emissions of carbon monoxide. Carbon monoxide is not a significant air quality problem in the UK so oxygenated petrol is not the preferred solution. Hence in this report the tern 'cleaner petrol' will be used to refer to petrol meeting the EU Year 2005 specification.

WORLD-WIDE AND UK EXPERIENCE OF CLEANER PETROL

Reformulated petrol, of the oxygenated variety, accounts for over 25% of all petrol sold in the US. At present MTBE is used as the oxygenate, though this is to be phased out in some US States by 2002. After this date, refiners are considering the use of ethanol and other MTBE replacements if US federal regulators continue to require oxygenates be used (AEA, 1999a).

Cleaner petrol is or will be available in Italy, Germany, Sweden, Denmark and France, many of whom are assisting the introduction of this fuel through the use of differential fuel tax incentives. In the UK, promotion of cleaner petrol has been spearheaded by supermarket petrol retailers (including Sainsbury's and Tesco) who have retailed low benzene petrol since the mid-1990s.

All UK refineries now produce petrol meeting the EU's Year 2000 requirements, which include a maximum of 1% benzene. However, until 2005, suppliers will be able to market grades with sulphur limited to 150 ppm. From 2005, the maximum sulphur limit will be reduced to 50 ppm. Therefore, all petrol will be 'cleaner petrol' as defined in this report from 2005. Several companies are already marketing grades which can be classed as cleaner petrol.

Vehicles

VEHICLE TECHNOLOGY

In principle, cleaner petrol can help reduce emissions from petrol vehicles fitted with a catalytic converter. As even low levels of sulphur present in vehicle's exhaust gases can reduce the effectiveness of a catalyst, the low sulphur content of cleaner petrol grades may extend the life and increase the efficiency of both catalytic converters and advanced on-board diagnostic (OBD) systems.

New technologies such as gasoline direct injection (GDI) offer potentially significant improvements in fuel economy. Since 1998, Mitsubishi have been marketing a 1.8 and 2.4 litre GDI engine which is currently used in the Carisma car. The company plans to develop the engine for use in a new model which is expected to appear on the Japanese market early in 2000 (AEA, June 1999).

These new engine technologies will require the use of exhaust after-treatment to control the regulated emissions. Advanced technologies such as NO_x traps and direct injection engines will be used to meet future vehicle emissions and fuel efficiency goals. Ultra low sulphur petrol (<50 ppm – mandated from 2005) is a key requirement for the introduction of advanced exhaust after-treatment systems. Some "Lean NO_x" and "NO_x adsorber" catalyst systems, used on gasoline fuelled direct injection engines, are intolerant of sulphur. Compliance with emissions requirements over the full useful life of the vehicle may require sulphur free fuels (maximum in the range of 5 to 10 ppm) (ACEA, 1998).

VEHICLE APPLICATIONS

The market for cleaner petrol is potentially very large as road transport petrol sales represents around two-thirds of all conventional road fuel sales in the UK.

FUEL CHARACTERISTICS

In many countries, the use of oxygenates has been encouraged in petrol. These high octane components can reduce the aromatics content and lower emissions of carbon monoxide. This reformulated petrol is favoured in areas and countries where a reduction in CO is required. This is the case in some US States. As the UK does not have a CO problem, oxygenated fuels are not required.

In the UK, low sulphur and benzene reformulations are preferred. The main components (99.8%) of these types of cleaner petrol are paraffinic, naphthenic and aromatic hydrocarbons. Benzene may be present in concentrations up to 1% by volume. Small quantities of additives such as anti-oxidants, detergents and oxygenates may be present from time to time.

FUEL SUPPLY & INFRASTRUCTURE ISSUES

Cleaner reformulations of petrol require further refining than ordinary grades. The extra processing is either achieved by adopting a more severe refinery operation or by investing in additional refinery facilities. Both these strategies make cleaner petrol more expensive to produce than ordinary unleaded petrol.

The spare forecourt tankage arising from the phase-out of leaded petrol in 2000 and the possibility that demand for Lead Replacement Petrol will decrease over the next 5 years provides new tankage space for new fuels or fuel grades.

The limited nature of forecourt space is an important issue for cleaner petrol. Even if fiscal incentives were in place, some retailers might be reluctant to supply both ordinary and cleaner grades in parallel. Many retailers would be more likely to either retain the

conventional formulation or convert fully to cleaner petrol in order to reduce demands on forecourt space and tankage (Tesco, 1999).

Environmental Impact

VEHICLE EMISSIONS

As is shown in Charts B2 to B17, light-duty vehicle emissions using cleaner petrol show only marginal improvement in NO_x and hydrocarbons. Carbon monoxide emissions show no significant change and are actually worse for cleaner petrol in one test (see Table E3). However, the main motivation for introducing low sulphur petrol is to improve the performance and longevity of catalyst after-treatment systems.

FUEL CONSUMPTION & LIFE-CYCLE EMISSIONS

There is no significant change in fuel consumption and carbon dioxide for cleaner as compared to ordinary unleaded petrol, **overall life-cycle emissions of carbon dioxide are not expected to significantly change**. However, it is the view of the motor industry that the advent of cleaner grades of petrol (<50 ppm sulphur) will indirectly assist with the introduction of fuel economy measures such as gasoline direct injection (GDI); the latter is predicted to reduce future vehicle carbon dioxide emissions by up to 15%.

SAFETY ISSUES

There are no additional safety issues associated with cleaner grades of petrol.

Market Acceptance

STANDARDS AND REGULATIONS

At present all petrol conforms to EN 228:1999 which includes the Year 2000 requirements of EU Directive 98/70/EC. This has reduced the levels of benzene and sulphur in UK petrol compared to previous years. In addition leaded-petrol has now been banned from general sale in the UK which will reduce airborne levels of lead still further.

Further to the EU 2000 Standards, tighter limits will come into force in 2005 (see Table B1). This will ensure that all petrol in of the 'cleaner petrol' variety by 2005. In parallel with EU legislation, the Motor Industry in their World-Wide Fuels Charter has been proposed for a 2005 cleaner petrol specification which would cover the EU, the US and Japan. These fuel recommendations include the harmonisation of future limits and includes a lowering of the sulphur content to below 30 ppm, which goes beyond the EU 2005 levels agreed (ACEA, 1998). The USA has decided to reduce the federal limit on the maximum sulphur in petrol to 30 ppm from 2004.

A 100% take-up of cleaner petrol is mandated by 2005 to meet the EU's 2005 petrol specifications. The 2005 EU fuel specifications mean that the current advantages of using cleaner petrol will be the norm by 2005.

Table B1: **Typical Composition and Standards for UK Petrol**

	Pre 2000 Av UK Unleaded		Ordinary Petrol limits	EU Standards 2000 limits	EU Standards 2005 limits
Standard			EN 228		
RVP summer kPa	74	max	80	60	60
Olefins % v/v	10	max	n/a	18	18
Aromatics % v/v	33	max	n/a	42	35
Benzene % v/v	2.3	max	5	1	1
Oxygen % m/m	0.1	max	2.7	2.3	2.3
Sulphur/ppm	200	max	500	150	50
Octane RON		min	95	95	95
Octane MON		min	85	85	85
E100 % v/v	54	min		46	46
E150 % v/v	85	min		75	75
Source	(1)		(1)	(2)	(2)

Sources: (1) UKPIA, 1998 (2) EU, 1997

ECONOMIC ISSUES

The current UK fuel duty rates for cleaner petrol are the same as for conventional unleaded petrol (47.21p per litre + VAT). No separate duty rate has been announced for cleaner grades.

Cleaner petrol costs more than conventional grades reflecting the increased production costs. For example, Tesco's City Petrol costs 3 p/litre (approx.) more than their conventional petrol grade and Green*ergy*'s current retail price premium is 2 p/litre. Thus, there is no current financial incentive for consumers to switch to the fuel.

Cleaner petrol which has been on sale in Finland since 1994 has benefited from a tax duty differential of 0.7 p/litre compared to conventional petrol. This has helped cleaner grades of petrol attaining nearly 100% of total petrol sales. This demonstrates the role that differential duties have in encouraging cleaner fuel use.

The general view of suppliers and retailers of cleaner petrol, is that, for a market to be established quickly, the pump price of cleaner grades will have to be the same as for conventional unleaded petrol. To achieve this, a fuel duty differential of around 2 p/litre would be required (Tesco, 1999; Q8, 1999; Green*ergy*, 1999c).

At present, the market share of Tesco's City Petrol stands at only around 1% of the company's total fuel sales. As petrol represents over 80% of fuel sales at super-market filling stations and, in general, represents around two-thirds of conventional fuel sales, there exists a potentially vast market for cleaner petrol.

With an adequate excise duty incentive all fuel retailers would switch to cleaner petrol as soon as possible. The impact of changes in the March 1998 budget of 2p/l lower duty on ULSD rising to 3 p/l in the March 1999 budget resulted in sales of ULSD going from 2% of total diesel in May 1998 to virtually 100% 15 months later.

Analysis by Green*ergy* suggests that a 2 p/litre price premium would result in around 15% of petrol sales being clean petrol. With a premium of 1 p/litre, they predict that over 50% of petrol would be of the cleaner petrol type. With a fuel duty differential of 2 p/litre, they estimate that 30–50% of the unleaded petrol market would switch to cleaner petrol within a year. (Green*ergy*, 1998 & 1999a). However, for a major switch to cleaner petrol the distribution system requires all the companies concerned with a terminal to switch. Hence any incentive would have to be pitched at ensuring that all companies switch at once.

Anecdotal evidence suggests that the public are confused by the increasing number of petrol grades available on the market. This is not helped by the various trade names under which cleaner petrol has been sold (e.g.s 'Low Benzene Petrol', 'City Petrol'). To address this possible confusion, consumers might benefit from clearer descriptions of cleaner petrol grades and information on their benefits.

Additional Comments

Vehicles do not require adjustments to use cleaner petrol. Its increased use is primarily dependent on the production and refining capability and fiscal incentives.

The year 2005 European 50 ppm sulphur limit for petrol will significantly reduce sulphur levels in all petrol used within the EC. However the motor industry contend that further reduction of sulphur levels limits (<10 ppm) would improve the efficiency and longevity of after-treatment systems and assist the introduction of technology to reduce fuel consumption (such as GDI).

A study undertaken for the Canadian government argues that although there is a cost involved in introducing gasoline with a lower sulphur content, this is outweighed by the benefits. The research concluded that the introduction of low sulphur fuel in Canada would cost $2.4bn. However, the benefits in Canada of reduced health expenditure would be more than double this figure. The research supports the moves to reduce fuel sulphur levels which are currently being undertaken around the world (AEA, June 1999).

Cleaner Diesel

Cleaner diesel as defined in this section is now the standard diesel sold in the UK.

Its inclusion in the report is to demonstrate the advantages of cleaner diesel used in conjunction with exhaust after-treatment systems.

The advantages of cleaner diesel for automotive applications include:

- **reduced regulated vehicle emissions;**
- **advantages available to the majority of existing diesel vehicles;**
- **permits the use of catalysts and particulate traps.**

The disadvantages associated with cleaner diesel include:

- **some cleaner diesel fuels can occasionally result in poor vehicle performance;**
- **the low maximum density of Ultra Low Sulphur Diesel increases fuel consumption.**

GENERAL CONCEPT

Cleaner diesel, referred to as 'Ultra Low Sulphur Diesel' (ULSD) and sometimes by the trade name 'city diesel', has lower levels of sulphur and aromatics than ordinary diesel. For the purposes of this report, the term 'cleaner diesel' refers to all diesels which have sulphur levels below 50 ppm.

Conventional diesel has itself been improved by the introduction of tighter European legislation to reduce sulphur levels coming into effect in 2000 and 2005. Cleaner diesel is therefore being introduced against a background of overall diesel improvement. Even though virtually all diesel sold in the UK from 2000 will have 50 ppm sulphur or less, this section focuses on the benefits of exhaust after-treatment systems which require the use of low sulphur fuels.

UK AND EUROPEAN EXPERIENCE

Within Europe, the use of cleaner diesel was led by the Scandinavian countries. One of the first users of cleaner diesel in the UK was the Swedish company Stora. As part of their environmental programme, Stora's UK contractors were required to use the fuel from 1992.

Early UK adopters of cleaner diesel included FirstBus, the Go Ahead Group, British Airports Authority, TDG Williams Distribution and the Lane Group who provide transport services on behalf of the Body Shop and London Transport. The latter's bus depots that opted to use cleaner diesel reported less complaints from the public regarding visible pollution (smoke) from buses.

The supermarkets played a significant role in promoting cleaner diesel to the forecourt during early stages of introduction. Cleaner diesel was introduced by Sainsbury's in 1995 at 11 London stores and by Tesco at 50 London stores in September 1997. Most of the oil companies initially focused on depot based fleets rather than forecourts.

Incentivised by a fuel duty tax differential, all diesel sold now conforms to ULSD standards (<50 ppm sulphur).

In contrast to the widespread introduction of cleaner diesel, the use of after-treatment systems in conjunction with cleaner diesel is less common. Several UK projects are underway which clearly demonstrate the emissions benefits which can be achieved with particulate traps for heavy-duty use (e.g. Refuse Collection Vehicles in Westminster and London Bus companies). A few manufacturers are beginning to fit particulate filter systems as standard on new passenger cars.

Cleaner Diesel – Vehicles

VEHICLE TECHNOLOGY – ENGINES

No modifications to diesel engines are required in order to use cleaner diesel and no major technical barriers exist regarding the fuel's introduction. However, the performance of and emissions from diesel vehicles are predicted to improve through the introduction of new diesel engine systems.

In addition to the conventional Direct Injection (DI) and In-Direct Injection (IDI) systems, new diesel technologies include Common Rail Injection. This is a diesel fuel injection system which employs a common pressure accumulator, called the 'rail'. In the common rail system, the injection pressure is independent from engine speed and load. The injection parameters can thus be freely controlled which allows for reductions in engine noise and NO_x emissions.

Fiat, which claims the credit for developing the first common rail injection system on its JTD engine, have developed the second generation version and fitted it to a 1-litre diesel engine in a Fiat Punto. The system, christened Multijet, fulfils the promise of common rail by taking advantage of higher speed technologies to deliver multiple injections of fuel at greatly reduced time intervals (AEA, June 1999). Other manufacturers are also developing common rail systems.

VEHICLE TECHNOLOGY – AFTER-TREATMENT SYSTEMS

A significant advantage of using ultra low sulphur diesels is that they allow the use of tailpipe catalyst technology. Catalyst systems are designed to reduce emissions of the organic fraction of diesel particulates, hydrocarbons, carbon monoxide and nitrogen oxides. Low sulphur diesel also allows the use of the continuously regenerating trap (CRT) which offers a method of reducing particulates to levels well below Euro 4 standards (DieselNet, 1999).

PSA Peugeot Citroen has unveiled a diesel particulate filter system which is expected to go into production in 2000. The filter reduces particulate emissions from diesel fuelled cars to levels required by the year 2005 EU emission standards (Euro 4). Peugeot will fit the filter on a 2.2 litre, common rail diesel engine which will be the first modern, mass-produced automobile equipped with a diesel particulate filter (DieselNet, 1999).

Diesel catalysts and particulate traps offer the potential for significantly reducing vehicle emissions to levels well below those offered by the use of ULSD alone. In fact, for some vehicle types, particulate and NO_x emission levels specified by Euro 4 and beyond appear to be impossible to meet without the use of advanced after-treatment systems. The use of cleaner diesel is therefore a pre-requisite for the attainment of future Euro 4 and 5 legislation for diesel vehicles.

For heavy-duty engines, integrated after-treatment system design is still at an early stage with many technical obstacles remaining. For example, to meet the Euro 4 NO_x limit, technologies such as Exhaust Gas Recirculation (EGR)may be required. They are already common on car and van diesel engines and are set to appear on truck diesels. However, their use aggravates particulates, making after-treatment PM filtration even more of a necessity (AEA, March 1999).

Cleaner Diesel – Fuel

FUEL CHARACTERISTICS

The composition of all diesel is specified by EN 590: 1999 which is implemented in the UK as BS EN 590. In addition, ULSD has to comply with the 1998 Finance Act (see *Standards and Regulations*). Although there is no specification for so called 'city diesel', the term has now become a generic name used for many low sulphur diesels, with a sulphur content similar to ULSD. Taken as a whole, cleaner diesels have greatly reduced heavy hydrocarbons and sulphur that are present in ordinary diesel.

One fuel characteristic of cleaner diesel which turns out to be particularly important is fuel viscosity. Although BSEN 590 allows a large variation in viscosity, evidence suggests that a viscosity that is too low will cause fuelling, idling and hot start problems, as well as poor engine response rates. Taken together, these problems can lead to over-compensation of the throttle by the driver and hence increased fuel consumption (see Case Studies).

FUEL SUPPLY

A few companies, including Shell, Total, ELF, Futura and Greenergy, have been supplying ULSD since 1997. By the start of 1999, several oil companies were supplying low sulphur diesels, primarily to urban fleet operators and some had announced that they were joining Sainsbury's and Tesco in marketing it through their service stations. These included ELF and Murco who were among the first forecourt retailers to introduce ULSD at their 800 forecourt locations.

By August 1999, all oil companies had begun to supply the fuel and by October 1999, well over 96% of all the diesel sold in the UK was ultra low sulphur diesel. The market for cleaner diesel saturated at the end of 1999.

INFRASTRUCTURE ISSUES

The great advantage of cleaner diesel is that it is entirely compatible with conventional diesel, so existing tankage and filling stations can be used.

ULSD requires additional refining to reduce levels of sulphur and aromatics. However, the UK is fortunate that UK crude oil is naturally low in sulphur which has allowed refining of ULSD without prohibitively expensive conversion of the refining plant.

Cleaner Diesel – Environmental Impact

VEHICLE EMISSIONS

Tests conducted at Millbrook show that reductions in all the regulated vehicle emissions for cleaner diesel as compared to pre-ULSD (> 50 ppm) grades. These are of the order of CO (15%), THCs (22%), NO_x (14%), PMs(25%) (Millbrook, MBK 971000).

Charts B18 – B33 show the vehicle emissions for heavy-duty vehicles using both ULSD and ULSD in conjunction with a CRT. Major reductions are achieved for heavy-duty vehicles through the use of after-treatment; for the bus data shown, CO (~85%), THCs (~78%), NO_x (~12%) and particulate emissions (~82%) as compared to ULSD. The use of some after-treatment systems is dependant on the use of ultra low sulphur fuels.

FUEL CONSUMPTION & LIFE-CYCLE EMISSIONS

Due to the reduced density of ULSD, the volumetric fuel consumption tends to be 1.5–2% higher than with standard diesel. However, some operators have reported increases in fuel use of up to 10%. This is a result of how the fuel was produced (by additional refining or by blending with kerosene) which produces a fuel with viscosity and density levels extremely close to the minimum allowed by BSEN 590 (FTA, 1999) (see Case Study 1).

Despite the marginal increase in fuel consumption, the reduced density actually decreases CO_2 emissions slightly (about 1%). This is explained by the higher hydrogen/carbon ratio in low density fuels when other fuel parameters are kept constant (ACEA, 1998). Though vehicle emissions of CO_2 are slightly reduced, this is balanced by a slight increase in production emissions due to extra refining required. Overall, for fuels with good performance, no significant changes in life-cycle CO_2 emissions are predicted for heavy-duty vehicles using ULSD with a CRT.

New engine technology promises to reduce CO_2 and other emissions if used with advanced after-treatment. For example, Peugeot's common rail engine used in the 306, 406 and soon the 206 models is reported to provide a fuel consumption on the combined cycle of 4.1–4.9 ltr/100km, which results in CO_2 emissions of around 136 gms/km (AEA, Oct 1999).

SAFETY ISSUES

There are no additional safety issues associated with cleaner diesel and ULSD.

Cleaner Diesel – Market Acceptance

STANDARDS AND REGULATIONS

Ultra Low Sulphur Diesel is a sub-group of diesels as specified by BSEN 590 (see Table B2). The specifications to which ULSD must adhere must satisfy the following criteria which are defined in the 1998 Finance Act. This stipulates that, in addition to BSEN 590 standards:

- The sulphur content must not exceed 0.005% by weight or is nil.
- The density must not exceed 835 kg/m^3 at a temperature of 15°C.
- Not less than 95% by volume distils at a temperature not exceeding 345°C. (Customs & Excise, 1998)

Table B2: Typical Composition and Standards for UK Diesel

Parameter	Conventional Diesel	Limits	BS EN 590 standard	ULSD standard	EU Standards 2000	EU Standards 2005
Centane No.	51	min	49		51	51
T95 (deg.Celcius)	348	max		345	360	360
Polyaromatics (max) % v/v	8	max			11	11
Sulphar (max)/ppm	336	max	500	50	350	50
Density @ 15°C (kg/m^3)	847	min	820			
		max	860	835	845	845
Viscosity mm^2/s		min	2.00			
		max	4.50			
Source	(1)		(3)	(1)	(2)	(2)

Sources: (1) Typical composition – UKPIA, 1998 (2) EU, 1997 (3) current British Standards

The EU has introduced mandatory changes to the specifications for both the years 2000 and 2005. By 2005 all diesel sold in the UK will have a maximum 50 ppm sulphur, the same sulphur limit as current ULSD. These forthcoming fuel specifications will themselves lead to reduced vehicle emissions from all diesel vehicles. Therefore, many of the *relative* advantages of cleaner diesel which are apparent at present will be reduced, as the specifications of 'ordinary' diesel formulations are themselves improved. Convergence is expected in 2005.

In parallel with EU legislation, the Motor Industry has proposed a World-Wide Fuels Charter for a cleaner diesel specification which would cover the EU, the US and Japan. These fuel recommendations include the harmonisation of future limits and includes a lowering of the sulphur content to below 30 ppm, a density range of 820–840 kg/m^3, a viscosity range of 2.0–4.0 mm^2/s and a poly-aromatics content of 2.0%m/m. These standards go beyond the EU 2005 levels agreed (ACEA, 1998).

ECONOMIC ISSUES

As a result of the compatibility of ordinary and cleaner diesel, there is no need for new forecourt fuelling facilities, and virtually no vehicle cost penalties, unless after-treatment systems are used. Providing the fuel has a good quality lubricity additive to counter some of the removal of some of the components which help lubricate the fuel pumps in conventional diesel, there should be no additional maintenance costs.

In March 1999, ordinary diesel increased by 6.14p a litre. ULSD only increased by 4.96p to 47.21p per litre, increasing the fuel duty differential as compared to ordinary diesel to 3p/litre. This reflects the lower emissions associated with ULSD and was a further incentive to encourage all users of diesel to switch to this cleaner fuel. To be eligible for fiscal support, the specifications to which ULSD must adhere must satisfy the criteria outlined above.

After-treatment systems fitted as standard on vehicles are only beginning to appear on the market. Current costs of CRT systems for heavy-duty use is around £4,000–£5,000 per vehicle. DETR is analysis shows that, for buses, this increases the private lifetime costs by 3–4% (see LEAF model in Section C). As the market grows, it is likely that system costs will b reduced. By 2005, CRT systems are forecast to cost in the region of £1,500–£2,000. However, it is difficult to predict costs of integrated systems which will reduce both particulates and NO_x which are still under development.

MARKET POTENTIAL

USLD now accounts for essentially all diesel sales in the UK.

The market potential for after-treatment systems is expected to grow significantly over the next 5 years in order that diesel vehicles will be able to comply with Euro 4 vehicle emission standards for NO_x and particulates. By the end of 1999, some manufacturers were already beginning to market light-duty production vehicles with diesel after-treatment systems.

Additional Comments

Diesel engine makers agree that for heavy-duty diesel vehicles, the Euro 4 PM limit will probably require a downstream particulate filter such as the catalyst-dependent continuously regenerating trap (CRT) (AEA, March 1999). The motor industry contend that these and future after-treatment technologies will require diesel fuels with sulphur levels well below the current ULSD 50 ppm limit and may require levels <10 ppm.

Natural Gas (NG)

The advantages of natural gas vehicle (NGV) operation include:

- **Reduced regulated and unregulated vehicle emissions.**
- **Reduced noise levels.**
- **Existing national fuel-distribution grid.**

The disadvantages associated with natural gas vehicles include:

- **High capital costs of natural gas vehicles (compared to conventional vehicles).**
- **Undeveloped network of national fuel-refuelling stations.**
- **Reduced vehicle payload.**

GENERAL CONCEPT

Natural gas can be used within an internal combustion engine. The gas can be stored on-board a vehicle either in compressed (CNG) or liquefied (LNG) form. Bi-fuel, dual-fuel and dedicated gas engine vehicles are available.

UK AND EUROPEAN EXPERIENCE

Over 1.2 million Natural Gas Vehicles are in use world-wide in over 40 countries with Argentina (450,000), Russia (>300,000) and Italy (300,000), Canada and USA (70,000) operating the largest fleets. Excluding Italy, Europe has over 8,500 NGVs, serviced by 175 compressor filling stations. European countries with the most advanced NGV fleets and infrastructure are Italy, Germany, Holland, Sweden.

Gas vehicles were first introduced in Italy before the second world war, with small vehicles focusing on the commuter market, sponsored by government subsidies. The Argentinean government promoted the fuel via subsidies in response to severe air pollution problems in Buenos Aires and to conserve their own supplies of oil for export (IEA, 1999).

British Gas introduced the fuel in the UK, and helped to establish the NGVA, which now represents the NGV industry. Following the de-regulation of the British gas industry in 1997, a number of gas utilities are currently interested in promoting NGVs in the UK.

There are currently over 750 NGVs on British roads in both the private and public sector fleets. The UK's NGV programme is presently spearheaded by the Natural Gas Vehicle Association (NGVA) and its members which consists of vehicle, engine and components manufacturers/suppliers, gas suppliers, fleet operators, research organisations and educational institutions.

Over 32 UK local authorities and 52 UK organisations use or have used at least one CNG vehicle. These include the Automobile Association, Birmingham City Council, British Airports Authority, Boots, DHL International, FirstBus, Government Car Service, London Boroughs of Sutton and Merton (see Case Study 7), Camden Community Transport (see Case Study 5) , NatWest Bank, Newbury Buses, Rugby Borough Council, Southampton Citybus, UPS, White Arrow and Safeway. The Body Shop also uses heavy-duty NGVs operated by Lane Transport.

FirstBus operated the UK's first CNG bus in Bristol in 1996. Since then, Southampton Citybus have introduced 16 CNG buses into their fleet, 10 of which were dedicated gas vehicles supplied by Dennis Specialist Vehicles. The project was made possible by the assistance of Hampshire County Council, the DETR and the EC funded ENTRANCE project. The NG filling station was financed, installed and operated by British Gas.

The UK is also leading the utilisation of liquefied natural gas (LNG) within Europe with trial vehicles run by Edinburgh District Council, BOC Distribution Services Ltd. and Transco. Perkins successfully designed and installed ten 12-litre engines into ERF-EC12 Trucks which operate on LNG for Marks and Spencer. The vehicles have been operating since December 1997 within the London Area.

Natural Gas – Vehicles

VEHICLE TECHNOLOGY – ENGINES

NGVs can either be bi-fuel, dual-fuel or dedicated.

The bi-fuel option utilises a traditional spark ignition engine, optimised for burning petrol, but able to run on natural gas or petrol at the flick of a switch. There are already several microprocessor gaseous fuel systems that are able to comply with advanced emission requirements. However, compared to petrol operation, bi-fuel vehicles can experience 10–15% power loss at 'wide open throttle' when in NG mode.

The dual-fuel system provides a gas/air mixture which is ignited by a small injection of diesel fuel. Gas provides between 0–90% of the fuel depending on operating conditions. Caterpillar have just launched a range of dual-fuel vehicles in the USA. However, dual-fuel is the least technologically developed gas option, hence emission and performance data are not readily available.

Dedicated gas engines maximise the benefits offered by gaseous fuels and provide vehicle performance similar to conventional fuels. Dedicated NGVs also show the maximum reductions for regulated and carbon dioxide vehicle emissions due to natural gas's relatively low carbon content (75% NG, 87% diesel) and its high octane number allowing a higher compression ratio which improves thermal efficiency. Light duty allow for optimised catalysts to be used.

Lean-burn operation is quite feasible with CNG as demonstrated by the FirstBus CNG bus in Bristol. Further development, however, must await the commercialisation of De-NO_x

catalysts. When these are available, CNG already has the advantage of having ultra low sulphur levels necessary for De-NO_x operation.

VEHICLE TECHNOLOGY – FUEL STORAGE

CNG is normally stored on-board a vehicle in high pressure cylinders at a pressure of about 200 bar. The weight of fuel and tank will typically be about 4 times heavier than petrol or diesel. Cars are typically fitted with a single cylinder of around 90 litres capacity (16 kg gas; equivalent to around 5.2 gallons of petrol). Vans are usually fitted with two 90 litre or a single 120 litre gas cylinder, equivalent to 7 gallons petrol (British Gas, 1998).

Steel is the most common material used for CNG tank construction. The weight of the tanks is approximately 1 kg per litre of tank capacity. New composite materials and structures are increasing being used which include 'hoop-wrapped' and fully wrapped fibre composites. However, the lower weight options are costly which prevents the widespread use of these materials (British Gas, 1998).

A less established alternative is liquefied natural gas (LNG). There are about 1,000 LNG vehicles in operation world-wide, mainly in the US. LNG is stored in smaller, vacuum-insulated fuel tanks to maintain the low temperatures required (–160°C). Though LNG has increased costs and handling problems compared with the more established CNG option, LNG substantially increases storage efficiency which results in around three times the vehicle range compared to CNG operation.

VEHICLE APPLICATIONS

Bi-fuel vehicles have two fuel tanks, which results in a vehicle weight and space penalty, but provides them with an increased range. For example, the Vauxhall Combo van normally has a payload of 598 kg. In the bi-fuel version, the payload is reduced by 20%, but the vehicle has an extra range of 200 km. Most light-duty NGVs (<3,500 kg) are bi-fuel conversions from petrol engines.

Compared to bi-fuel, dedicated NGVs have a larger weight and volume penalty due to the NG fuel tankage required to give a vehicle range similar to conventional fuels. Therefore, dedicated vehicles tend to be large panel vans, trucks, buses and HDVs where the extra weight and volume of the gas tanks is less of a problem. Trucks up to 44 tonnes have been successfully produced for the commercial market.

Table B3: **Effect of using CNG on passenger capacity of a bus**

Fuel	Tank Capacity (litres)	Storage pressure (bar)	Extra Weight for 500 km operating range	Reduction in passenger capacity compared to diesel
Diesel	200	1	–	–
CNG	1300	200	1200 kg (steel) 800 kg (composite)	~6 persons
Comments			Roof mounted	Due to weight rather than space restrictions

Source: AEGPL, 1998

For dedicated NGVs, the additional weight associated with on-board storage presents a significant barrier for particular vehicle types. 3.5 tonne GVW panel vans, weight sensitive haulage and refuse collection vehicles are the most affected. However, where the short range is not a problem, there are no technical barriers to the use of CNG for these vehicle types.

VEHICLE AVAILABILITY

A large number of NGVs are already commercially available in the UK. These are either after-market conversions, OEM approved conversions or OEM vehicles. In Europe, over 20 companies offer vehicle conversion to bi-fuel NGVs and 6 companies manufacture high pressure storage cylinders for CNG.

In the UK, the after-market, bi-fuel car conversion companies include Autogas 2000, Hendy Lennox Power Products Ltd., Millbrook, Tickford Engineering Ltd. and TMC Gas Power Ltd. The models are converted using vehicles from most well known car manufacturers. OEMs also produce CNG cars and light-duty vans for the new vehicle market. Examples include the Volvo bi-fuel S70/V70 passenger car, the Vauxhall bi-fuel Combo Van and the Ford Transit.

At least two dedicated NG cars have been developed for the European market. These include models from Honda, equipped with a catalyst which is reported to have 1/10th of the US ULEV emission standards. BMW have in series production a 3-series passenger car with bi-fuel CNG operation and Fiat have two cars and vans which are dedicated to natural gas operation. BMW are also currently operating demonstrator LNG cars in the 3, 5 and 7 series.

For the heavy-duty market, several OEM companies produce or convert dedicated NG gas engines and/or vehicles. These include Cummins, Dennis, Dennis Eagle Ltd., ERF Ltd., Iveco Ford Truck Ltd., Perkins, Scania Great Britain and Volvo. (See Case Studies 5, 7 and 8).

Natural Gas – Fuel

FUEL CHARACTERISTICS

Natural gas used in the UK comes predominantly from the North Sea oil and gas fields. The main constituent of natural gas is methane with small amounts of propane and other hydrocarbon gases.

In this country the composition is consistent and high in methane, but there are significant differences in natural gas quality throughout Europe and the rest of the world, where the methane content can vary from 80 to 99% of the total. This high variability in methane content can adversely affect vehicle operability, as the engine management systems cannot cope with large changes in gas composition.

Natural gas makes an ideal vehicle fuel for combustion engines because of its high octane rating and low VOCs. Natural gas has a number of advantages over conventional fuels. Being a gas it requires no vaporisation and accordingly mixes easily with air prior to combustion. This offers lower idling speeds, better performance, easier cold starting and a more complete combustion which all help to reduce tail-pipe emissions. The high octane rating of gas means that compression ratios can be set high which increases efficiency (ETSU, 1996). Developments in the USA and Japan indicate that gas engines with optimised combustion can reduce fuel consumption by up to 10% over petrol.

FUEL SUPPLY

Natural gas is the second most abundant fossil fuel, after coal. The ratio of proven reserves to annual production is double that of petroleum. Proven and probable UK reserves of natural gas have been estimated to last approximately 40 years. New interconnectors between the UK, mainland Europe and the Russian gas fields could further extend supplies for UK use for another 100 years. The long-term outlook for natural gas is therefore substantially better than that of oil.

The fuel consumed by conventional UK road transport is equivalent to around the energy content of 65% of total UK gas sales i.e. 15 billion Therms. Diesel is used principally by fleet operators and this demand is close to 4 billion Therms per year. The most appropriate use of gas for transport is in replacing conventional fleet fuels in urban areas; approximately 4% of the vehicle population. Gas demand would increase by around 5% which is well within the gas transmission grid capacity and the available resources. The likely increase in Internet shopping will increase the number of delivery vehicles.

LNG is used in the UK as a peak supply for high pipeline demands and British Gas is the sole supplier. British Gas also own a number of LNG tankers which were put into service many years ago to supply some Scottish towns with 'mains gas'. Elsewhere oil producing locations will liquefy and ship natural gas if the gas produced cannot be sent via pipeline.

INFRASTRUCTURE ISSUES

NG re-fuelling technology is well proven and has been successfully demonstrated in numerous demonstration and real-world projects. Refuelling systems can be one of two types:

- **'fast-fill'** – this system uses natural gas under high pressure and requires a cascade of storage vessels in which the gas is stored at around 250 bar. The systems fill the vehicle in about the same time it takes to fill with conventional fuels. The dispensers look similar to petrol and diesel pumps and can be located with traditional liquid fuel pumps. Each dispenser can fully refuel about 200 vehicles a day;

- **'slow-fill'** – this system consists of a compressor unit above ground which 'trickle charges' an NGV over a number of hours. This enables vehicles to be left parked to refuel when not in use, and is suitable for operators who can leave their vehicles over a period of time to refuel. Each unit can refill one or two vehicles at a time. Slow-fill facilities can be fitted to a domestic gas supply, giving private motorists the ability to refuel at home.

One of the main barriers is the low number of publicly accessible refuelling points for NGVs. Though the UK has the advantage of there being an existing national pipeline grid, at present there are only around 24 CNG filling stations.These are mostly concentrated in the Midlands and the South East, but the number and geographic spread is expected to grow substantially. British Gas is the largest single NGV fleet operator with 300 bi-fuel Transit vans and has 9 refuelling stations.

Growth of the existing NG re-fuelling infrastructure is being assisted by gas companies such as British Gas Fuels which has launched a programme in which they finance the construction and operation of new filling stations, and the operator only pays for the gas as it is dispensed. Infrastructure development could be further assisted by the distribution company Transco who are in a strong position to set up a refuelling network. However, under existing legislation, they are not allowed to install gas refuelling equipment for NGV fleets.

In the near-term, a market may emerge for urban NGV fleets using bio-gas generated from MSW (Municipal Sewer Waste), such as in Stockholm and Goteburg or from landfill gas which is being considered by Leeds City Council. Jeff Seisler of the ENGVA sees a major potential for the use of bio-gas in the future, as oil prices and waste disposal problems increase (IEA, 1999).

Environmental Impact

VEHICLE EMISSIONS

Within the light-duty sector, with the exception of total hydrocarbons, the regulated emissions are significantly reduced for NGVs with dedicated vehicles showing the largest emission reductions. For cars when compared to the current petrol baseline, the reductions are CO (>43%) and NO_x (>35%) and particulates are negligible. For a panel van when compared to a diesel baseline, the reductions are CO (>75%), NO_x (>90%) and particulates are virtually eliminated.

For dedicated heavy-duty vehicles, with the exception of total hydrocarbons, the regulated emissions are significantly reduced for NGVs. When compared to the current diesel baseline, the reductions for a bus are around CO (>52%), NO_x (up to 86%) and particulates (>68%).

Though total hydrocarbons are significantly higher for bi-fuelled light-duty and all heavy-duty vehicles, over 80% of these emissions are composed of methane which has a low potential to react in the atmosphere to create ground-level ozone (summer smog). In addition to reduction of the regulated emissions, CNG emissions have very low levels of sulphur oxides and do not contain benzene or 1,3-butadiene.

Natural gas vehicles have significantly low noise levels and engine vibration. Tests in and outside of cabs indicate greater driver and pedestrian acceptance. Heavy goods vehicles e.g. Perkins engines in the BOC fleet show a reduction from 68dB to 60dB equivalent to an executive car. This is a major benefit to fleet operators giving access to stores and the use of refuse collection vehicles in the early mornings which also helps in reducing congestion.

FUEL CONSUMPTION & LIFE-CYCLE EMISSIONS

For most vehicle types, fuel use (MJ/km) is increased for NGV operation. However, because of fuel's low carbon content, NGV operation reduces the life-cycle CO_2 emissions for light-duty vehicles. However, methane is an important greenhouse gas (GHG) and the emissions of methane from the vehicle, refining and distribution processes must be included when calculating the effect of NGVs on global warming. (This report follows the approach taken by DETR and uses a GWP of 21 for methane).

After increased methane emissions are accounted for, NGVs show an improvement over life-cycle GHG emissions of around 20% for cars and car-derived vans as compared to a petrol baseline. GHGs are slightly increased when compared to diesel for light-duty vehicles. These figures will improve as more dedicated gas engines are brought on to the market with optimised catalysts. For Panel Vans and heavy-duty vehicles >3.5 tonnes, total GHGs are comparable or slightly increased when compared to diesel operation.

Calculation of the life-cycle emissions of LNG requires the compression and liquefaction energy to be taken into account. These emissions are then added to the vehicle and fuel production emissions as with CNG.

SAFETY ISSUES

The characteristics of natural gas, the installation and structure of the fuel containers when compared with diesel or petrol make it safer than conventional fuels in a crash situation or fire (borne out by actual experience in the Netherlands):

- The gas is non-toxic and naturally odourless (additives are required to add odour).
- As NG is less dense than air, in the event of a leakage, the gas will rise and disperse into the atmosphere.
- The diffusion coefficient of gas is high in comparison to conventional fuels; it therefore diffuses rapidly into the ambient air.
- The flammability limits of NG are narrow in comparison with conventional fuels; this reduces the chance of a flammable mixture occurring.

The NGVA runs robust accreditation schemes, ensuring approved suppliers have appropriately trained staff at all levels. The schemes cover design and installation for vehicles, systems, components and refuelling stations and extends to include maintenance and repair. International and European standards cover all aspects of the industry.

Market Acceptance

STANDARDS AND REGULATIONS

Natural gas fuel composition has to conform to reference fuels specified by an EC fuel directive which allows for some variation in methane content (85% to 100%). The development of NGV equipment standards (for storage cylinders, on-board systems, refuelling connectors and fuel stations) has also been a key priority of the European NGV industry. The agreed specifications will form the forthcoming CEN Standards due for early 2000.

In the past, there has been a problem with the Construction & Use regulation which meant each NGV has to obtain a Special Order before it could be used on public roads. The legislation has been amended to a General Order which removes the need for each vehicle to be assessed individually. The CEN Standards will override this legislation when it comes into effect within the next 12 months which will remove the unnecessary regulations for NGVs.

The NGV community are recommending that an additional non-methane hydrocarbon (NMHC) standard is added to the existing EU emission limits for light-duty vehicles (<3.5 tonnes). A heavy-duty engine standard has already been agreed. This would recognise that most of the hydrocarbon emissions from NGVs are methane (over 80%) which does not readily react in the atmosphere to create ground-level ozone (smog). Compared with petrol, diesel and LPG, NGVs have significantly lower ozone forming potential (European and US measuring standard comparative study, 1999).

The weight penalty associated with CNG reduces the pay-load that can be carried by the vehicle. This can reduce revenue for the operator who may already be working within tight economic constraints. To overcome this barrier, vehicles with a greater payload capacity are often purchased. However, the vehicle then incurs a higher rate of vehicle excise duty.

To address this issue it is suggested that some form of weight dispensation is introduced. One potential mechanism for achieving this, would be to allow alternatively fuelled vehicles to exceed their Gross Vehicle Weight (GVW), by the incremental increase in weight associated with the alternative fuel and its storage system. The exceedance would be subject to vehicle manufacturer and the appropriate regulatory body's approval.

ECONOMIC ISSUES

The main barriers to the use of NGVs are their high capital cost and the lack of a refuelling infrastructure. Dedicated NGVs, are more expensive to build due to diseconomies of scale. The additional costs for a bus' storage tanks alone can be as high as £10,000. At a volume of 5,000 units per year. CNG adds 10–15% to the cost of a passenger car. Typical NGV costs are shown in Table B4. To reduce this economic barrier, for approved vehicles, the Powershift programme will subsidise up to 75% of the additional vehicle cost.

Table B4: Extra capital costs of CNG vehicles

	Standard Vehicle	Standard Cost	Current Extra Cost	Anticipated Future Extra Cost
Particular Models	Volvo V70/S70 car	£20,000	£1,700	
	Vauxhall Combo Van 1.4	£7,700	£1,900	
General Vehicle Types	Cars and light-duty vans	£1,700–£3,500*		
	Midi-Bus	£60–80,000	£30,000	£4,000
	Single Decker Bus	£100–110,000	£25–30,000	£15,000
	Refuse Truck	£80–100,000	£12–20,000	£3,000
	Mid-range Truck	£40–50,000	£10,000	£1,500

(Sources: NGVA, 1996, *British Gas, 1998)

In Italy, the lower cost of gas and reduced running costs have been the main motivation for operators to switch to gas powered vehicles. In Italy there is no fuel duty on natural gas. Belgium and the Netherlands also have zero fuel duty on CNG. (After EU harmonisation in 2000, they may adopt the new permitted minimum duty rate of 8p/kg).

In the UK, the Government is committed to maintaining the fuel duty differential between gaseous fuels and diesel to at least the differential that existed in July 1997 (DETR, 1998c). Natural gas is taxed by weight (per kg) and not per litre. In the 1999 Budget, the road fuel duty for natural gas was cut from 21.3p to 15.0p/kg. The NGVA recommend a target fuel duty of 8p/kg, the EU permitted minimum (from 2000).

At forecourts, NG retails at around 61p/kg. This is equivalent to approx. 41p/litre for petrol or 45p/litre of diesel. For fleet bulk purchase, the price for NG can be as low as 57p/kg depending on contract arranged with supplier.

DETR Leaf analysis shows that, from a lifetime public cost perspective, CNG vehicles are associated with increased costs as compared to conventional vehicles. The increase is in the region of 24–55%, depending on the vehicle type. For light-duty vehicles, lifetime private costs for CNG operation are up to 5% higher than petrol operation (zero vehicle purchase subsidy) and up to 5% cheaper with a 50% Powershift grant. In contrast, NG bus operation shows an increase in lifetime private costs of around 25% (0% Powershift) and an increase of around 14% even with 50% Powershift funding.

The high capital cost of refuelling stations also act as a barrier to NG. Costs range from ~£2000 + £51 per month (for a 'Fuelmaker' which can fuel two vehicles overnight) to over £150,000 for a system which provides fast-fill for a whole fleet (e.g. Merton Fleet – See Case Study 7). British Gas and Mobil offer packages in which they finance the construction of the refuelling station and the operator only has to pay as the gas is dispensed. British Gas installed a re-fuelling station for a 16 bus fleet in Southampton at a cost of around £250,000.

In Germany, 50% of the costs associated with refuelling infrastructure are available from government. The subsidy is up to a maximum of DM500,000 (approximately £175,000), which means that sites which benefit cost up to £350,000, enough for a major fleet of HGVs. This measure has helped double the number of refuelling stations to over 110 which are used by around 5,000 vehicles (NGVA, 1999). By the end of 2000, 2000 stations will be servicing a predicted 10,000 NGVs.

Italy has made £70 million available for infrastructure development. Subsidies are available for infrastructure and vehicle purchase for NGVs. This is in parallel with a mandate that all public vehicle purchases must include 10% of these vehicle types. This will increase to 50% by 2003. France is adopting a similar policy approach.

Japan has one of the most ambitious NGV programmes and with Germany, Italy, Sweden and the USA they see NGVs as a global market, and natural gas as a main stream fuel along with petrol and diesel. On a domestic level, they aim to have over 200,000 vehicles by 2003 and 2,835 refuelling stations by 2005. Government support is given to vehicle manufacturers and there are 50% grants for the additional cost of vehicles and 66% grants for the refuelling stations. By October 2000, all manufacturers will have a full range of vehicle available (International NGV Conference and Exhibition, Yokohama).

MARKET POTENTIAL

In countries with an established refuelling infrastructure passenger cars represent the main market opportunity. However, in other countries, NG is seen as more suitable for large fleet vehicles which can return daily to their own centralised refuelling facilities. In the UK, the prime market for CNG is seen as urban buses, followed by municipal HGVs such as refuse collection trucks, and then by medium duty delivery fleet vehicles and finally light-duty fleets (IEA, 1999).

At present, UK demand is coming from transport operators and local authorities. However, the market is constrained by the supply of NGVs from vehicle manufacturers and also by the economics of supply. The focus has been on depot based heavy-duty NGV fleets due to the availability of heavy duty dedicated engines, and to the economies of scale that can be achieved which can provide large fleets significant fuel and maintenance cost benefits. Hauliers have also started using gas for fleets operating into urban areas, e.g. Safeways and BOC delivering to Marks and Spencer on a trial basis only (IEA, 1999).

US studies suggest a global NGV population of 20 million vehicles by 2025. From known data, growth can be expected in most countries in the EU. If the Government sets the fuel duty for CNG at the EU recommended minimum and maintain the differential for at least 5 years, the NGVA project the number of NGVs operating in the UK in 5 years could be around 30,000 vehicles (see Table B5).

Table B5: **Current and projected numbers of NGVs (dedicated & bi-fuel) operating in the UK**

Vehicle type	mid-1999	5 year projection	15 year projection
Cars	45	3,000	25,000
Taxis	3	300	1,500
Car derived vans	60	6,000	20,000
Buses	50	450	5,000
Panel Vans & HGVs	455	20,000	30,000
Others	140	500	2,000
Total	**Approx. 750**	**30,250**	**83,500**

(Source: NGVA, 1999)

Additional Comments

A commonly held vision of the future for road transport is the advent of a hydrogen infrastructure to support fuel cell vehicles. However, significant barriers remain to achieve this objective. These include the capital investment and the technological challenges required to create a hydrogen production, transmission and distribution network.

One solution would be to form a transition technology to a hydrogen economy by the use of the extensive natural gas network. If gas re-fuelling points are installed at forecourts and depots, 'reformers' could be used to generate hydrogen from the natural gas on-demand. Reformers are a very well established 'off-the-shelf' technology and are one of the cheapest ways of generating hydrogen. Thus the natural gas re-fuelling infrastructure which is being developed today could well become the infrastructure that delivers the hydrogen for a future generation of hydrogen fuel-cell vehicles.

Another option to utilise NG for fuel cell vehicles is to reform the gas on-board the vehicles. The advantage would be the use of a developed natural gas infrastructure though this would have to be balanced against the extra weight of the on-board reformer. Either way, the use of NGVs provides extensive driver and operator experience of using a gaseous fuel and keeps open the option of fuel cell vehicle systems.

Liquefied Petroleum Gas (LPG)

The advantages of using LPG for automotive applications include:

- **reduced regulated and unregulated vehicle emissions;**
- **reduced operating costs;**
- **reduced noise levels.**

The problems which remain are:

- **high capital costs of LPG vehicles (dedicated and vehicle conversions);**
- **under-developed national fuel distribution system;**
- **wide variation in fuel composition across Europe;**
- **some restrictions in use in confined spaces within continental Europe.**

GENERAL CONCEPT

Liquefied Petroleum Gas (LPG) can be used within an internal combustion engine, the gas is stored on-board a vehicle as a liquid under moderate pressure. The gas can be used in bi-fuel or dedicated LP gas engine vehicles.

UK AND EUROPEAN EXPERIENCE

There are currently over 4 million road vehicles using LPG in countries such as Italy (over 1 million), Holland, former Soviet Union, Japan, USA, Australia (each with between 300–400 thousand) and significant numbers in Mexico, USA, Japan, Australia, South Korea and Canada. In Europe, the LPG vehicle parc numbers around 2.0 million vehicles).

Table B6: Overview of European LPG Fleet (1997, 2000)

Country	LPG fleet size	(1997) LPG fleet size	(2000) Comments
Italy	1,100,000		Majority of fleet are light-duty vehicles and buses
Netherlands	362,000		
Poland	310,000		
All other European Countries (excluding UK)	290,500		
United Kingdom	1,500		
Approx. 13,000 75% cars, 25% light-duty commercial vehicles/vans			

Source: World LP Gas Association LPGA, 2000

In the UK there are around 13,000 LPG vehicles used on public roads (LPGA, 2000). The majority of these are light-duty vehicles, most which have been converted to bi-fuel operation. Around 24 LPG buses are either being demonstrated or carrying fee-paying passengers, and there are about 25,000 fork lift trucks operating on LPG.

Table B7: LPG vehicles subsidised by Powershift (EST, 1999)

LPG Vehicle Type	Number of vehicles purchased through Powershift Years 1–3
Car/Car-derived van	519
Van	303
Bus/Minibus/Truck	48
Total	**870**

Public sector projects which use LPG vehicles are located in Bath, Southwark, Cambridge City Council, York, Government Car Dispatch Agency, Hampshire Police, City of Westminster, London Borough of Bromley, Oxford City Council, Cheshire County Council, Suffolk County Council and Stratford-upon-Avon. The largest single current LPG fleet will be operated by Humberside Police who are in the process of converting 460 police vehicles to LPG over the next 4 years. As of July 1999, around 180 vehicles had been converted.

In the private sector, Lex Vehicle Leasing, Securicor and DHL operate LPG vehicles, DHL use 25 LPG powered Transit vans as part of their London fleet. Arriva Bus and Coach have 4 dedicated SB220 LPG buses either in-service or for demonstration throughout the country. One vehicle has entered into service on Chester's park and ride route alongside a conventional bus which has enabled a direct comparison with diesel operation (see Case Study 10).

In the Netherlands, LPG is considered a 'conventional' motor fuel. Most filling stations along the motorways supply LPG and 10% of the passenger cars use LPG. The autogas consumption for this sector amounts to around 15% of the total fuel consumption in passenger cars. Several major Dutch cities have transport fleets operating on LPG (Amsterdam, Groningen, Eindhoven and Hertogenbosch) and it is common for public transport companies to buy diesel buses for conversion to LPG.

Vehicles

VEHICLE TECHNOLOGY

Automotive LPG equipment consists of:

- a fuel storage system;
- a fuel distribution and/or injection systems into the engine;
- an engine modified/dedicated to run on LPG fuel.

Cars and light duty vehicles which can operate on LPG are most often conversions designed to run in bi-fuel mode. Whereas older bi-fuel conversions often had poor performance (the engine being optimised for petrol operation), recent conversions utilise electronically controlled dry gas injection systems. The advantage of bi-fuel operation is that vehicles are less reliant on a fully developed LPG refuelling infrastructure and are able to continue operating in areas where LPG is unavailable.

Heavy Duty Vehicles which operate on LPG can do so using one of two technologies:

- **LPG stoichiometric engines** – The development of LPG stoichiometric engines uses a spark ignition engine. The LP gas is either added to the air flow or injected in gaseous or liquid form. This approach is already used for commercially manufactured heavy duty vehicles.
- **LPG lean-burn engines** – this allows a significant improvement in fuel consumption as well as increased engine efficiency. This approach is more suited to large truck applications. However, these engines are not available in Europe at present.

To get the best emissions performance from an LPG vehicle, a dedicated engine is required. The advantages are not available to bi-fuel operation because a compromise is required for the two fuels. The last few years have seen increased interest from motor manufacturers in dedicated LPG engines. DAF, for example, have recently put a dedicated LPG bus with three-way catalyst on the market (see Case Study 10).

Current bi-fuel and dedicated LPG vehicles have an engine performance similar to conventional fuels. Engine performance improvements are found for HDV conversions to LPG and include a better torque at low rpm than diesel and an extended engine life due to the cleaner fuel and lower engine stress (AEGPL, 1998). Conventional petrol catalyst technology can be used for light-duty LPG vehicles, whereas heavy duty vehicles use catalyst systems which are optimised for LPG.

VEHICLE APPLICATIONS

LP Gas can be used in most vehicle types, either in bi-fuel or dedicated engines. LPG is most suited for use in passenger cars, light-duty vans and buses, all of which are already being operated in several European cities. Heavy-duty vehicle applications are also being demonstrated and include vehicles used for city distribution and refuse collection.

VEHICLE AVAILABILITY

LPG is suited to light-duty vehicles due to the low cost of conversion. A wide range of LPG cars and light duty vans are already available in the UK. These are either after-market conversions, OEM approved conversions or OEM vehicles.

The after-market car conversion companies include Autogas 2000, Environmental Gas Company, Hendy Lennox Power Products Ltd., Key Autogas Ltd., Millbrook, Power Torque Engineering Ltd., Tickford Engineering Ltd. and TMC Gas Power Ltd. The models are converted using vehicles from most well known car manufacturers.

The OEM approved conversions and OEM vehicles are supplied by Vauxhall, Volvo and Metrocab. Vauxhall currently have a range of purpose built bi-fuelled cars and vans. These include the Astra, Vectra, Omega cars and the new Astravan and Combo light-duty vans. Volvo also manufacture the bi-fuel S70/V70 passenger car. Dedicated LPG buses and heavy duty vehicles are supplied by Arriva Bus and Coach, DAF Bus International, and Scania Great Britain.

Fuel

FUEL CHARACTERISTICS

Liquefied Petroleum Gas is a mixture of propane and butane. It arises in the extraction of natural gas (approx. 3% of the gas) and as a by-product of refining. LPG has the advantage of being composed of simple chemical compounds which can easily form a homogeneous mixture with air, thus allowing a more complete combustion than is the case for conventional fuels. In principle, this leads to a reduction in vehicle emissions.

By volume, LPG has a lower energy density than conventional fuels. The energy density of LPG is typically a third less than for petrol (23.6 MJ/litre as compared 32.3 MJ/litre). This means that a greater volume of fuel is required. However, by mass, LPG contains around 8% more energy. Thus less fuel mass is required for a similar vehicle range, but this advantage this is offset by the extra weight of the tank required.

Across Europe, there is a wide variation in LPG composition. Whereas LPG contains more than 90% propane in the UK, in Italy this can be as low as 20%. With early conversions, this affected the ability of vehicles to travel throughout Europe on LPG. However, with modern self-learning systems, this problem has been largely overcome and most new dedicated LPG engines are able to tolerate a wide variation in LPG composition as defined by EN 589.

LPG is stored as a liquid under moderate pressure (at 4–12 bar). The tanks are heavier than conventional petrol or diesel tanks for the same range. Though the tanks occupy similar volume to petrol and diesel tanks, this can present a problem for bi-fuelled vehicles where two tanks have to be accommodated. LPG tanks can only be filled to 80% capacity to allow for expansion of the product.

The extra mass of the fuel system slightly increases the fuel consumption and imposes a small weight, and payload penalty. Most dedicated LPG buses have their tanks fitted to the roof, but they can also be placed in the chassis, under-floor or attached to each side of the frame. The extra weight for an LPG HDV, compared to diesel, is around 250 kg for an operating range of 500 km (AEGPL, 1998).

Table B8: **Comparison of passenger carrying capacity of diesel and LPG bus**

Fuel	Tank Capacity (litres)	Storage pressure (bar)	Extra Weight for 500 km operating range	Reduction in passenger capacity compared to diesel
Diesel	200	1	–	–
LPG	600	9	250 kg	0 to 3 persons

(Source: AEGPL, 1998)

FUEL SUPPLY

The UK currently uses 2,000–3,000 tonnes of auto-LPG per annum. Adequate supplies of LPG are available for road transport applications, both for current consumption and for a demand of up to 300,000 tonnes per annum. In addition, there is a surplus of 4.0 million tonnes from oil fields in the North Sea. World LPG production is increasing while demand remains fairly constant. Projected production capacity is therefore predicted to be able to meet significant extra demand from the transport sector

In the UK, the distribution of LPG from the distribution terminals to the refuelling points is achieved by the use of pressurised road tankers. At present, the vehicles used are under 17 tonnes in weight.

INFRASTRUCTURE ISSUES

The main barrier to the increased use of LPG in the UK is the limited network of refuelling locations. Although there were around 500 LPG filling stations in 1980, the number decreased, as did demand, due to the high fuel duty on LPG. By August 1999, there were only 200 public access refuelling points in the UK.

With the renewed interest in LPG, the number of filling locations has now increased to around 300, with a forecast of 500 by the end of the year 2001. This contrasts to the situation in other countries such as Italy where 1,700 refuelling sites are available and the Netherlands where 2,200 sites have been installed. Europe as a whole has a total of around 7,000 refuelling sites.

In addition to the above public access sites, over 300 depot based LPG facilities have already been installed by the industry. Although these service a relatively small number of vehicles, depot based refilling will remain an important element in the development of the automotive market.

The expansion of LPG refuelling infrastructure is most likely to occur through publicly accessible forecourts. In November 1999, out of the 250 public access refuelling sites, only 20 were forecourt installations. The majority of the new future installations planned will be sited on existing forecourts and the major oil companies aim to install around 500 LPG refuelling points on their forecourts by 2001.

Environmental Impact

VEHICLE EMISSIONS

All the regulated emissions are reduced for LPG operation when compared to conventional fuels. For light-duty vehicles, CO is reduced by over 20%, THCs by >40% and NO_x by >30% (as compared to petrol). For heavy-duty engines, CO is reduced by >90%, THCs by >80% and NO_x by about 60% (compared to diesel). Particulate matter (PMs) is virtually eliminated from LPG vehicle emissions.

LPG bus operation results in reduced noise levels when compared to a conventional diesel vehicle. Noise levels recorded for LPG bus operation have been found to be at least 2–3 dB quieter than diesel operation. This represent a reduction of around 50% perceived noise levels (AEGPL, 1998).

LIFE-CYCLE EMISSIONS AND FUEL CONSUMPTION

Volumetric fuel consumption of LPG is about 60% higher than with diesel fuel due to LPG's low energy density. However, this is balanced by LPG's high energy content by mass, as well as its low carbon mass fraction.

In tests there is a 10%–15% reduction of life-cycle CO_2 emissions for light-duty vehicles as compared to petrol operation and a approximately 5% reduction when compared to diesel. For heavy-duty vehicles, however, life-cycle CO_2 emissions are comparable to diesel (see Charts B2–B25).

SAFETY ISSUES (HEALTH AND SAFETY EXECUTIVE, 1999)

Overall, the dangers associated with the use of LP gas in automotive situations are no greater than those associated with diesel or petrol fuels. In fact, studies have shown that the frequency of accidents has proven extremely low throughout Europe and even lower than those of conventional vehicles (AEGPL, 1998).

However, the gas presents *different* risks due to the properties of the gas. These include:

- Gas releases on disconnection. The LPG filling nozzle maintains a gas-tight seal with the vehicle filling point, but a small volume of gas may be released on disconnection.

- Refuelling accidents. Risks associated with vehicle impact damage to dispensers and driving away with the dispensing nozzle still connected to the vehicle. Risks can be reduced by the use of pressure/flow sensors, raised kerbs and breakaway couplings.

- Possible overfilling. On-board LPG tanks must have at 20% ullage (free space) to allow for possible liquid expansion. 80% stop-valves are fitted to the gas cylinders to prevent over-filling.

- Gas spillage and build up. In the event of a gas spillage, the gas tends to sink to the lowest level of its surroundings such as drains pits or within a semi-enclosed vehicle space. Some EU countries ban LPG vehicles from underground car parks to prevent any risk of gas build-up and LPG vehicles are not permitted to use the EuroTunnel.

Market Acceptance

STANDARDS AND REGULATIONS

The fuel quality of auto-LPG has to comply with the current European Standard for automotive LPG (EN 589). The standard does not precisely define the composition of the gas mixture, but allows four grades which vary with vapour pressure. These grades have been introduced to cope with the different climatic conditions which exists across Europe (AEGPL, 1998).

From October 2000, for all fuels, tests of heavy duty engines will have to undergo the ETC test cycle (which involves urban, rural and motorway driving). LPG HDVs will be required to use two reference fuels to prove the self adaptability of the engines to different LPG compositions on the market. In the longer term this latter requirement may not be required.

At the current level of use, the existing regulations are considered adequate to ensure the safety of automotive applications of LPG. The position of the Health and Safety Executive includes the following recommendations that "safety standards at gas refuelling facilities should continue to be ensured by use of existing standards [....] but this arrangement should be reviewed if and when the availability of gas on petrol station forecourts significantly increases" (Health and Safety Executive, 1999).

ECONOMIC ISSUES

The additional costs associated with LPG operation include:

- the higher capital vehicle cost – the unit price is higher for LPG vehicles;

- the safety regulations require extra safety measures and investment (e.g. suitable ventilation systems, detection systems and modification of ground level electrical switches);

- the higher maintenance costs due to training, use of synthetic lube and catalytic converter replacement (for heavy-duty vehicles only).

The additional savings include:

- Lower fuel costs for light duty vehicles. For heavy-duty vehicles, savings are less certain.
- Reduced vehicle road tax for heavy-duty LPG vehicles.

In the UK, the switch to LPG is currently dictated by the potential cost savings for the user of the vehicle. As there are significant additional capital costs associated with LPG vehicles, the pump price of LPG and annual mileage is crucial in determining whether a cost advantage exists.

Currently, vehicles are converted to LPG at a cost of around £800–£1,500 for cars and vans and around £15,000 for bus conversions. For dedicated LPG buses, the extra capital cost is in the region of £25,000. The increased cost of LPG vehicles can be offset against reduced fuel costs and the subsidies are available to assist with LPG vehicle purchase or conversion (see Case Study 10).

LPG enjoys a lower rate of duty than conventional fuels. The duty rate was reduced in the 1999 Budget by 29% to its current levels of 15.0p/kg (approx. 7p/litre). Forecourt prices are around 36p/litre (approx. 71p/kg) which are typically about half those of petrol and diesel, and bulk prices can be as low as 28p/litre. Although the calorific value of LPG is low in comparison with petrol and diesel, LPG's lower price gives the opportunity to recoup the costs of the extra fuel required. (This is better for light-duty vehicles). For example, taking into account the reduced energy density, the price of LPG is approximately 49p/litre.

The DETR Leaf analysis shows that, LPG vehicles are more expensive than conventional vehicles, by about 21–39%, depending on the vehicle type. For light-duty vehicles, operating costs are broadly comparable with petrol operation (zero vehicle purchase subsidy) and up to 11% cheaper with a 50% Powershift grant. In contrast, LPG bus operation shows an increase in lifetime private costs of around 22% (0% Powershift) and an increase of around 14% even with 50% Powershift funding.

MARKET POTENTIAL

There has been a good take-up of LPG for cars and light duty vehicles within the *Powershift* Programmes (see Case Study 10). Indeed, over 70% of the vehicles subsidised through this scheme have been LPG. In the first three years of its operation, the *Powershift* programme assisted with the purchase of 870 LPG vehicles (EST, 1999). This suggests that the main UK growth market for LPG vehicles over the next 5 years is most likely to be in the passenger car and light-duty van sectors.

The development of light-duty LPGV market will be assisted by the increasing availability of high-quality bi-fuel and dedicated vehicles on the UK market (e.g. Vauxhall range). It will also be assisted by the expanding number of LPG refuelling points located at publicly accessible forecourts (although the continued investment by the fuel suppliers appears to be dependent on a further widening of the fuel duty differential versus petrol).

For LPG Heavy Duty Vehicles, the most promising market perspectives over the next 5 years are as follows (AEGPL, 1998):

- Public transport applications: e.g. city buses, inter urban buses, tourist buses. The AEGPL consider that replacement of 25% of the existing city European bus fleet by LPG would be achievable by 2005. It is expected that up to 500 LPG buses could be operating within UK urban areas by 2005.
- Urban HDV fleets: e.g. goods distribution in towns, refuse collection vehicles, local authorities fleets. LPG is particularly suited for use in refuse vehicles, city distribution and delivery trucks. However, there are at present no projections for the future vehicle numbers for these vehicle types.

Additional Comments

The demand for LPG vehicles is mainly coming from local authorities and urban fleets, driven mainly by the low price of LPG fuel. There is some push from the oil companies, but they are really focused on sale of their conventional fuels. However, there is a motivation to sell LPG because it is a by-product of refining and currently sold at low value for camping gas or domestic heating. Auto-LPG has a higher market value and it requires less investment than environmental improvements to conventionals fuels which require expensive refinery conversions (e.g. low sulphur diesel) (IEA, 1999).

Battery Electric

Battery powered electric vehicles have inherent advantages for the following reasons:

- **they produce zero-emissions at point of use;**
- **they can utilise renewable electricity so providing zero-emission (life-cycle) transport;**
- **they are quiet and low vibration in operation;**
- **the simplicity and reliability of drive train;**
- **the energy effciency of the electric drive system in stop-start driving compared to ICE vehicles;**
- **they can recover kinetic energy via regenerative braking.**

BEVs suffer from the following disadvantages:

- **High capital vehicle cost (e.g. due to high cost of batteries).**
- **Limited vehicle range due to the amount of energy which can be stored in batteries.**
- **Typical battery recharge time of 6–8 hours (slow charge).**
- **Increased vehicle mass from the battery pack which increases vehicle mass by 300–900 kg.**

GENERAL CONCEPT

Electrical energy can be stored in a battery on-board the vehicle. When required, electrical energy is drawn from the battery and converted to motive power by the use of an electric motor.

UK AND EUROPEAN EXPERIENCE

There are currently more than 28,000 BEVs in Europe. This figure includes circa 16,000 milk delivery vehicles in the UK, passenger cars and car derived vans, single seat micro cars and other commercial vehicles.

Table B9: European BEV Fleet by Country

Country	1997 BEV parc	Country	1997 BEV parc
Austria	480	Italy	950
Belgium	60	Netherlands	70
Finland	130	Norway	135
France	3,500	Sweden	400
Germany	2,200	Switzerland	2,500*
UK	17,393	**Total**	**27,800 (approx.)**

*includes approx. 1,000 single-seat micro-BEVs

Sources: Avere, European Automotive Research & DVLA, 1998

Electric commercial vehicles have been widely used in the UK in a number of specialist applications such as folk lift trucks, airport vehicles and the electric 'milk-float' delivery vehicle. Currently, milk-floats comprise the largest number of electric vehicles in the UK. Other than milk-floats, there are probably less than 100 modern electric vehicles in use in the UK.

Electric cars have been trialled and used in small numbers by the following organisations: Eastern Electricity, English Nature, Government Car Service, Ipswich Borough. Council, Luton Borough Council, National Power, Westminster City Council, Freelance (Toyota, Jersey), Peugeot Motor Company PLC, Coventry City Council, East Midlands Electricity PLC, Royal Mail Midlands, ScottishPower and PowerGen PLC. Electric buses have been introduced in Merseyside (Birkenhead), Bristol, Oxford and in the London Borough of Camden.

Table B10: **UK Electric Vehicle Population, Licensed for Use on the Public Highway**

Vehicle Type	Numbers	Comments
Cars	116	
Taxis	1	
Motorcycles	42	
Tricycles	32	
Light Goods Vehicles	581	Principally small milk floats
Goods Vehicles	11,843	Principally milk floats
Bus/Coach	73	
Agricultural	154	
Others	4,551	Vehicles such as tow tugs
Total	**17,393**	

(Source: DVLA, 1998)

Current UK BEV projects include the Coventry EV Project where 14 Peugeot 106 Electric cars have been on trial since 1997. Feed-back from project users subsequently led to the marketing of the 106E in the UK and to the launch of the electric Partner Van (see Case Study 4). Toyota have also initiated a BEV car demonstration programme in Jersey. The 'Toyota RAV4 Jersey Electric Vehicle Project' is trialling 5 electric RAV4s for 5 years from 1997, primarily for tourist use.

In Birkenhead, Merseytravel operate 6 battery electric buses on intensive urban bus routes. This scheme is funded by the EU Joule-Thermie programme and is described in detail in Case Study 9. The ASTI Project (run by Camden Community Transport in London) is operating three battery electric buses. The project, which began in January 1995, is funded by its partners, the EC LIFE Programme and the Department of Trade and Industry. Originally conceived as a community 'dial-a-ride' scheme for people without access to suitable transport, the project has extended its remit to include electric vehicles to reduce the health impacts on its passengers and pedestrians (see Case Study 5).

Vehicles

VEHICLE TECHNOLOGY

The general principle of a battery electric vehicle is relatively simple. Electrical energy from any source can be stored in a battery on-board the vehicle. When required, electrical energy is drawn from the batteries and converted to motive power by the use of an electric motor. Typically, batteries are used to power a motor using direct current (d.c.). An alternative is to convert the direct current from the battery to alternating (a.c.) using an inverter which then drives an a.c. power-train.

BEVs can be slow or fast charged. The most usual charging cycle is an overnight recharge which typically takes 6-8 hours. Newer "quick recharge" systems can take as little as 6 to 12 minutes to top up the charge to 40%. For faster charging rates, a higher voltage is required.

While the most common systems connect the supply and the vehicle using a conductive cable, inductive charging is being developed and has been successfully demonstrated.

The specific energy requirements for battery technology would appear to be the same as for petrol (i.e. 11700 Wh/kg). However, a direct comparison is unfair as electrical energy is more efficiently converted to kinetic energy in a motor than chemical energy is released for traction within an internal combustion engine. As a result, a specific energy of around 200 Wh/kg would provide a small BEV with a range comparable with a conventional passenger car.

The 'tried-and-tested' lead-acid battery is the most widely used for BEVs. Although they have a relatively low energy density (~30 to 40 Wh/kg), it is possible to build a vehicle that has a range of around 70-90 km using lead-acid technology. Although these cells are far from ideal in their energy storage and power delivery characteristics, their reliability, durability and widespread use are all attractive features, combined with an extensive maintenance network.

There remains much work to be done in developing an affordable rechargeable traction battery. The main obstacles at present are high cost, high weight, low energy density, short life-time and low charging and discharging efficiencies. There are also questions of safety with some types of cell and the issue of component recyclability, especially where rare metals are used.

Other common traction batteries include nickel-cadmium (Ni-Cd) and nickel metal-hydride (Ni-MH). Their relatively high energy density (50–60 Wh/kg) provides a significant improvement in the vehicle's performance and range. However, the nickel required makes them very expensive. Ni-Cds have the additional problems related to handling cadmium which is toxic and are difficult to recharge at high temperature. However, despite these problems, these batteries have proved to be suited to motive applications and are now preferred by many BEV manufacturers.

Another approach to BEV design concerns the motor technology. Most first generation BEVs used d.c. motors which are cheap, give high torque at low speed and are easy to control using semi-conductor technology. However, their efficiency of 80–85% and specific power of 150–200 W/kg (about a third of a petrol engine) does not represent the best possible performance of available motor technology. An alternative is to use the a.c. induction motor which has increased efficiency, is twice the specific power and is virtually maintenance free. Its disadvantage is the cost and complexity of the controller which needs both to act as an inverter (convert d.c. to a.c). and regulate the motor's speed.

Table B11: Specifications for a Selection of Battery Electric Vehicles

Company/BEV	Peugeot Scoot'elec	Peugeot 106E	Toyota RAV4	Nissan Altra	Iveco/Ford 49-12 Series	Gulliver Tecnobus
Vehicle Type	Scooter	Car/CD-van	Car	Car	Midi-bus	Mid-bus
Seating Capacity	2	4/2	5	4	12	9 seated
Gross Weight (kg)	115	1,387	1,936	2,077	4500	4400 (est)
Motor type	DC	DC	Perm. magnet	Perm. magnet	AC	DC
Battery Type	Ni-Cd	Ni-Cd	Ni-MH	Li-ion	Pb-Acid	Pb-Acid
Stored Energy (kWh)	0.6	12	27.4	32.4	31.9	42.1
Mass (kg)	39	255	450	360	1000	
Specific Energy (Wh/kg)	15 (est.)	47	61	90	28–38	
Top Speed(km/h)	45	90	125	120	65	32
Urban Range (km)	40	80	130	190 (est)	55	100
Energy Con. (Wh/km)	15	200		214	693	560
Purchase Price ($)	4,000	14,658	42,000			
Lease Price ($/month)		98 (battery)	499	2,520		
Where On-sale	W. Europe	West Europe	Japan, US	from 2000	UK project	Europe
Comments		Based on existing ICEV	Based on existing ICEV	designed for electric option	Vehicle conversion	Batteries replaced in mins

Source: Peugeot, '98 Atkin & Storey, 1998, Merseytravel 1999

To date, no one battery or power-train system has proved to be significantly superior than another. As a result, a large number of system designs are used for prototype and commercial BEVs. Table B11 shows a selection of BEVs which are either close to market launch or are commercially available.

In the future, it is very likely that BEVs will be designed from scratch rather than being conversions of current vehicle designs. This enables the optimum use of space for batteries and motors; reduces the aerodynamic drag and incorporates the use of new light-weight materials for the body and component parts. For example, Toyota's two-seater 'eCom' has kerb weight of just 790kg, including the 140kg battery pack. The micro-car has a range of 100–150 km and a top speed of 100 km/h.

VEHICLE APPLICATIONS

While most BEVs do not match the performance of conventional vehicles, current vehicles have a range and performance which is adequate for many specific, urban applications. They are particularly suited to drive cycles that are predictable, regular and less than 160 km per day (e.g. delivery cycles) especially in areas where low emission vehicles are preferred or mandated. BEVs are suited for use in commercial fleets (for small loads), company car-pools and within rental fleets. For individual transport, BEVs are most likely to be used as a second urban car.

The performance of BEVs also makes them ideal for use as urban short-term rental vehicles for passenger use where their limited range is unlikely to be an issue. Several European projects have been initiated which aim to make BEVs available for short-term use. Vehicles are accessed using state-of-the-art smart-cards and automatically monitored using satellite positioning systems and logistical software.

VEHICLE AVAILABILITY

Though most of the major motor manufacturers have developed BEVs, few have actively developed BEVs for the commercial market. Companies who have taken an active role and who have done more than most to promote BEVs include PSA Peugeot-Citroen, Toyota, Nissan, Ford and General Motors.

At present, the supply of battery electric vehicles in Europe is limited. The main supply is from the PSA Group with both Peugeot and Citroen offering small cars and vans (and electric scooters). OEM vehicles which are available are the Peugeot 106 Electric, the Peugeot Partner Van, the Citroen Saxo Electric and the Peugeot 'Scoot-elec'. Additionally, a limited number of vehicle conversions are offered by a small numbers of companies using established electric drive technology and low cost lead-acid batteries.

Fuel

FUEL CHARACTERISTICS AND SUPPLY

Electricity from any source can be used to recharge a BEV. Usually, for slow charging, grid electricity is used which is supplied at 240V a.c. (50 Hz). The charging unit comprises a transformer to reduce voltage and the current is then rectified to charge the cells using direct current. This is achieved either using an 'off-board' controller within the charging post or a controller 'on-board' the vehicle. For faster charging rates, a higher voltage is required.

To get an idea of the infrastructure requirements of large-scale BEV use, if 10% of all cars and vans were BEVs, the total would account for around 2.5 million vehicles. The annual electricity consumption of this fleet would be about 16 TWh, equivalent to a 5% increase in total UK electricity demand. In practice electric vehicles would recharge their batteries at night ready for use the following day. The electricity would therefore be supplied predominantly by base-load stations, which are at present largely under used. BEV charging would therefore have a proportionally small effect on the increased capacity required.

INFRASTRUCTURE ISSUES

The national coverage of the electric grid, makes it relatively easy to install recharge points when compared with other alternative fuels. In order to get a basic 'slow' charge in 5–8 hours for small BEVs, all that is required is access to a standard domestic 13A, 230V socket. Slow chargers are therefore suitable for home overnight recharging.

Fast charging in less than an hour is also possible with BEVs using widely available three phase 400V supply, which is typically found in most UK non-domestic buildings.

Connection to a high voltage line (e.g. 11kV) is also feasible. Fast charging has some bulk electrical infrastructure associated with it (including transformer and switchgear) and so is only cost effective when multiple points are being considered for a site. This option is more attractive for sites servicing several vehicles such as a fleet depot.

If an a.c. drive option is chosen, the drive-train requires the use of a dc/ac converter. Although this increases the costs of the control unit, the vehicle's converter can also act as an on-board charging unit able to accept a high power supply. In addition, the external charging hardware becomes simpler and therefore cheaper to install. If it is accepted that an extensive network of cheap fast charging points will greatly promote the use and range of BEVs, then the widespread use of on-board chargers, will reduce the overall infrastructure costs and promote the up-take of BEVs.

Whilst BEVs can be readily recharged overnight from home, there is a lack of available recharging infrastructure available during the day to compensate for the limited range of electric vehicles. Those people who wish to use electric vehicles but do not have their own driveways may face significant difficulties in getting electricity companies to install roadside recharging points. Additional charging posts would also allay the psychological fears of drivers that they will become stranded. Commercial vehicles normally require charging during the day in order to complete a full duty cycle.

Even where private users have purchased a BEV, it is by no means an easy matter to install a road-side recharging unit on a public road, in situations where a garage or off-road parking facilities are not available. For example, it took a London resident Simon Roberts, many years to have a charging post installed outside his house. This involved complex co-ordination of the local council, planning authorities and the local electric utility.

Another approach to recharging is to recharge the batteries off the vehicle. This method has been successfully demonstrated in Birkenhead where six Technobuses use battery packs which are recharged at base. When refuelling is required, the depleted battery pack is exchanged for a fully charged pack. (See Case Study 9).

Environmental Issues

VEHICLE EMISSIONS

The battery powered electric vehicle is essentially a **zero-emission vehicle**. Therefore, if we are to compare electricity with other transport fuels on environmental grounds we need to conduct a life-cycle energy and emissions analysis on the method used for electricity generation. Only greenhouse gas emissions have been compared in detail for the purposes of this report.

Modern electric vehicles are quieter than other road vehicles making them attractive for reducing noise in built-up areas.

FUEL CONSUMPTION AND LIFE-CYCLE EMISSIONS

Electric vehicles can be up to 40% more energy efficient than conventional ICE petrol vehicles for congested urban city driving since:

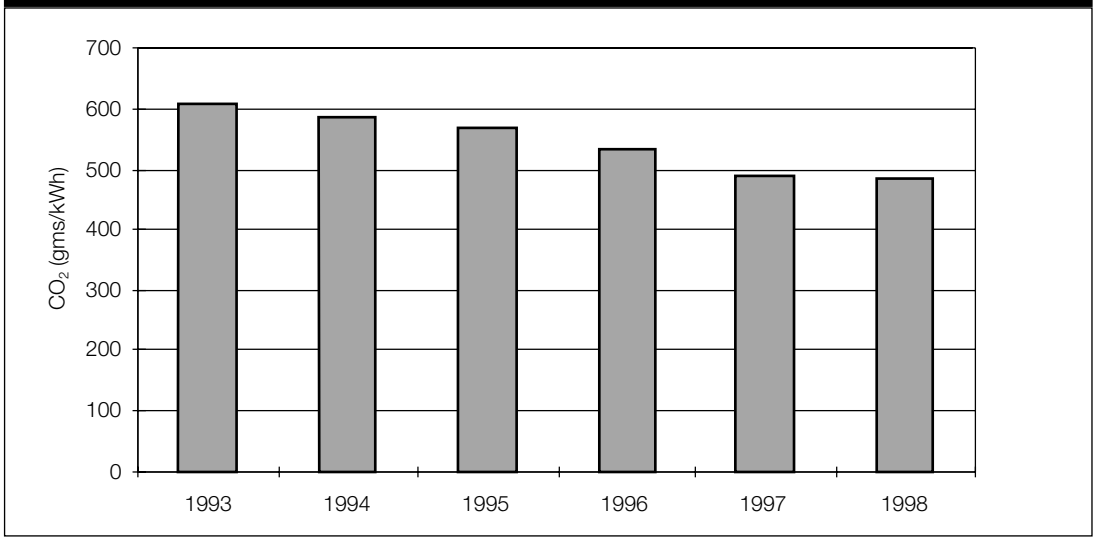
- An electric drive system is more energy efficient in stop-start, low speed driving compared with an ICE vehicle where the engine is normally optimised for a speed range of 80–100 km/h;
- they use almost no energy when stationary in traffic;
- they can recover energy via regenerative electrical braking (up to 20% recovered).

Since electricity is produced from other energy sources, these primary sources need to be considered when analysing the impacts of electricity use within the transport sector. In 1995, the average fuel mix included coal, nuclear, oil, hydro and gas. Since then, the proportion of coal has fallen and been replaced by cleaner fuels, new technology such as the high efficiency Combined Cycle Gas Generation (CCGT) gas fired stations.

The *life-cycle* data shows that CO and THCs are significantly reduced for the passenger car and bus. Particulate emissions are also reduced, for the passenger car and bus, although with an increase in SO_x emissions. NO_x emissions are significantly reduced for the bus, but can be significantly higher, in comparison with light duty petrol engined vehicles[1].

For *life-cycle* CO_2 emissions of grid-electric BEVs, all cases show a significant reduction, compared to a petrol or diesel operation. Using diesel as the baseline, the car and bus data show reduction in greenhouse gas of around 25%. CO_2 emissions are predicted to further improve with the introduction of cleaner generating plants (see Charts B2–B25).

Chart B1: UK Electricity Supply Carbon Dioxide Emissions Rends, 1993 to 1998



Grams of CO_2 per kWh of Electricity Supplied (Source: EA Technology, 1999)

1 Comparison basis:

1) Peugeot 106 Electric cf. Vauxhall Astra 1.4i gasoline. 1997 UK generating emissions mix.

2) 12m electric bus cf. Euro II diesel Olympian bus.

The benefits of BEVs to urban air quality are two fold, lowering the overall emissions and removing the release of those emissions away from the street-level in city centres where the greatest number of people work and live. Furthermore, predicted life-cycle emissions reductions are often underestimated as the equivalent emissions for other fuels are based on hot engine conditions and do not account for cold start conditions when a high proportion of emissions from ICE vehicles can occur.

SAFETY ISSUES

Electric vehicles should be at least as safe as existing Internal Combustion Engine Vehicles since they have no flammable fuels and meet normal vehicle safety standards. However, recycling issues associated with the use of rare metals such as Cadmium need to be addressed. Work in the US suggests that electric vehicles will be safer than ICEs on a range of issues including toxic fumes, fire risk, chemical burns, noise levels, refuelling risks and electric shock.

One potential advantage of BEVs, a reduction in noise, which can in some circumstances make it more hazardous for pedestrians who expect to hear approaching vehicles. An educational campaign and a degree of public learning will be required if BEVs are used in large numbers.

Market Acceptance

STANDARDS AND REGULATIONS

It is important that standards are developed for BEVs, their components and their infrastructure in order to minimise costs and ensure compatibility. This is especially important where recharging points are used by different makes of vehicle (Sterlini, 1998).

The few international standards so far developed relate mainly to essential safety issues, definitions and the measurement of vehicle performance rather than specific items such as the detailed arrangements for vehicle recharging. This partly due to the fact that many charging systems and connectors currently manufactured for commercially available BEVs are considered technically sound but too expensive for widespread introduction in the longer term. Alternative approaches to charging, such as inductive coupling are therefore being developed.

In the UK, standardisation activity for BEVs has recently been brought together in a single BSI committee, eliminating duplication of effort between electrical and automotive organisations. This allows full consultation between the electricity industry, the automotive industry, the electrical and mechanical component manufacturers and other interested parties. This contrasts with the European situation where a significant level of duplication exists in standardisation procedures (Sterlini, 1998).

ECONOMIC ISSUES

BEVs currently cost approximately 50–100% more than their conventional counterparts. For example, the initial purchase cost of a Peugeot 106 electric £13,680 (inc. VAT) to which the monthly battery leasing cost of around £60 must be added. If the battery is purchased outright, further capital expenditure will be required after around 5 years for battery replacement.

Saft data confirms this position and suggests that, excluding the battery, an equivalent BEV has a purchase price which is at least 1.8 times more than a similar ICEV. If the battery is leased, this amounts to around £600–700 per year or around 0.06–0.07 £/km. However, fuel and maintenance costs are reduced as compared to an ICEV, by about 20% and 60% respectively (Atkin & Storey, 1998).

BEVs have low fuel costs per km, due to the competitive price of electricity relative to other for fuels, and to the high efficiency of the vehicles themselves. For a battery electric bus, the energy (fuel) related costs per km are reduced by at least one third as compared to its diesel engined counterpart. For light-duty BEVs, fuel costs are reduced by well over one half.

Experience gained from the Coventry EV Project has shown that in comparison with their diesel counterparts, the BEVs used within the city have operated at a reduced fuel rate of 0.98p/km. This represents a fuel cost saving of approx. 3.1p/km. Over an annual mileage of 80 km per day (29,200 km per year), this represents a cost saving of around £900 per year.

The DETR Leaf model shows that, on a lifetime public costing basis, battery EVs are significantly more costly than petrol operation (by 56–77%). This is a significant barrier to the introduction of BEVs. However, due to the low operating costs which partly offset the high vehicle capital price, lifetime private costs are around 32–54% higher (depending on vehicle type). With 50% Powershift funding, this premium is reduced to around 15% for buses and 13% or less for light-duty BEVs.

A Peugeot 106E, costs approximately £18,500 to own for four years excluding servicing charges. With a maximum range of 88 km and a top speed of 88 km/h, accumulating the mileage necessary to compensate for the additional cost of a BEV would be difficult. Over 48,000 km would have to be covered per year averaging 133 km per day (which exceeds the range possible on one charge).

Total installation costs for a recharging point are in the order of £500–£2000, depending on the difficulty of the civil installation works. Fully installed fast rechargers cost about £7,000 per point (if associated with an on-board charging system, such as the Wavedriver system) or around £30,000 per point if associated with an off-board fast charger.

MARKET POTENTIAL

It is very difficult to accurately forecast some sectors of the future BEV market. With some certainty we can predict the continuing and highly successful use of electric milk floats and other specialist electric vehicles. However, for other vehicle sectors, it is unlikely that the number of passenger and non milk float light goods vehicles will exceed a thousand within

the next 2–3 years. Beyond that period, it is possible that the market take-up will accelerate, particularly if other major manufacturers can be encouraged to enter the market.

From 1996, PSA initially aimed to sell 2,000 cars per year rising to 10,000 annually by the year 2000. However, they have sold only around 2000 vehicles. These figures are significant as the Peugeot sales represent around half of the entire European market for electric cars. In the US, the picture is the same with only a few thousand BEVs being sold since late 1996.

In its first 3 years of operation, the Powershift has subsidised 96 BEVs (Car – 25; Car derived van – 50, Van – 12; Midi-bus – 9). Of this total, around 68 have been Peugeot vehicles (106E and the partner Van).

A recent FT Report predicts a "negligible world-wide demand for battery electric passenger cars in the *mainstream car sectors* over the coming decade. This leaves open the possibility that demand will increase for battery-powered commercial vehicles, buses and scooters – all sectors which have some characteristics that would make them more suitable for BEV applications" (Atkin & Storey, 1998).

Market research by PowerGen has shown that additional charging points are a key market requirement for purchasers of BEVs.

Currently, the main demand for BEVs is from local authorities, and is focused on smaller vehicles. Although the range/use of the vehicle is more important than the size, i.e. the market is restricted to vehicles which do not have a high daily mileage and that can return to an overnight recharging station. Vehicles include urban cars, small delivery vehicles and buses. The main motive for local authorities purchases is environmental but supported by electricity companies, for commercial reasons.

Partly in response to the poor uptake of BEVs by private motorists, new niche markets are being investigated for BEVs. If the conventional car buyer is not a likely candidate for BEVs for urban use, then perhaps these vehicles can be shared or rented on demand as part of the urban transport system. Projects which are experimenting with new methods of access to BEVs include Praxitele and CityCar short-term rental schemes where the traditional urban public transport has been enlarged through various complementary products.

Additional Comments

Electricity generated from renewable sources, which is becoming increasingly available, can be used by BEVs. To demonstrate the viability of 'zero-emission' transport, two car-derived vans have been put into service by the Northern Ireland electricity generating company 'B9 Energy' and are recharged with electricity from renewable sources. The battery-electric Citroen Berlingo vans, based at B9's headquarters, are normally recharged direct from the buildings own small (6kW) wind farm generator (which also provides energy for heat and light on the site) (AEA, April 1999).

Hybrid Electric

Hybrid-electric vehicles offer the following benefits:

- **the performance equivalent to an ICE vehicle;**
- **a vehicle range similar or greater than an ICE vehicle;**
- **a significant reduction in fuel consumption and CO_2 emissions;**
- **significant reductions in regulated emissions;**
- **zero-emission operation for limited range;**
- **reduced vehicle cost compared to BEVs.**

However, at present, hybrid-electric vehicles are associated with:

- **high capital cost compared to ICE vehicles;**
- **limited availability of vehicles;**
- **a multitude of design solutions.**

GENERAL CONCEPT

The internal combustion engine (ICE) vehicle can be combined with a battery electric traction system in what is called a '*hybrid-electric*' vehicle. A '*series*' hybrid uses a small ICE to generate electricity which powers an electric motor, so providing electric drive. In a '*parallel*' *hybrid*, the wheels can be either directly powered by the engine or from a battery powered electric drive-train.

UK AND WORLD-WIDE EXPERIENCE

In Japan, the Toyota Prius gasoline-hybrid has been on sale since 1997 and the company has announced that a European version will be on-sale from early 2000. Hybrid passenger cars are also being developed by Honda (the Insight), Nissan and Audi (the Avant parallel hybrid). Renault and Peugeot are developing (gas-turbine) hybrid versions of the Espace and 406 models. Renault has a 'production ready' version of its Express light commercial van. Volkswagen have developed the Chico, a compact family saloon built around a parallel power-train.

Table B12: **Specifications for a Selection of Hybrid-Electric Vehicles**

Company/HEV	Volkswagen Audi Duo III	Toyota Prius	ALTRA	Mercedes Evobus
Vehicle Type	Passenger car HEV	Passenger car HEV	12 m urban single deck Bus	13 m articulated single deck bus
Seating Capacity	5	5	85	64
Gross Weight (kg)		1,600 (est.)	20,000	13,420
Motor & Battery Type	Perm. Mag./Pb-A	Perm. Mag./Ni-MH		
Stored Energy (kWh)	7	1.9	59.6	
Battery Mass (kg)	320	75	2000	
Recharge time (hours)	As for petrol	As for petrol	As for petrol	As for diesel
Top Speed(km/h)	170	160	60	80
Urban Range (km)		1,300		800
Range on electric only (km)	36		10	
Energy Con. (MJ/km)		1.50	12.3	11.9
Purchase Price ($)	33,000	16,929		

(Source: Atkin & Storey, 1999)

In the UK, hybrid buses have been introduced in Portsmouth where FirstBus have converted a 20 seat Mercedes-Benz capable of operating for 25% of the working day in electric mode. The rest of the time the bus switches to diesel. The bus is powered either by its original diesel engine or by batteries manufactured by Chloride.

Five hybrid buses have been in daily operation in Aalborg, Denmark from March 1997 as part of the European JUPITER Project. They replace conventional diesel buses on one of the town's Citybus lines. These buses are capable of zero-emission driving mode which they operate for 15% of the time on the road.

In Genoa, Italy, ten hybrid buses are being used by the city's public transport fleet. The buses have a double propulsion system: electric propulsion and traditional gasoline propulsion. When the traditional propulsion system is in action the generator charges the battery. In urban areas, the engine is shut down and the battery power is used. Other heavy-duty bus and truck hybrid vehicle projects are underway in Leiden and Goteborg.

Vehicle

VEHICLE TECHNOLOGY

A technical break-through in hybrid vehicles has occurred in the last few years and several manufacturers are marketing HEVs. Hybrid vehicles equipped with ICEs operating at high efficiencies, and combined with a conventional BEV's power system offer the promise of improved fuel economy and reduced emissions. Hybrid vehicle technology possesses great potential to become the standard automotive technology during the coming decade.

Hybrid-electric vehicles require high power batteries with a smaller energy capacity than battery EVs. This eliminates all but three battery technologies: lead-acid, nickel metal-hydride and lithium-ion. On average, for passenger car hybrids, battery mass comprises only 12–18% of the vehicle's mass as compared with around 30–35% for BEVs.

Although several fuel-engine-drive train combinations are possible, the hybrids which have been first to reach the marketplace are 'gasoline-hybrids'. The Prius car is essentially an electrically assisted ICE fuelled by conventional petrol fuel. In the Prius, the battery is optimised for a high power delivery and not for long driving range, as is common for BEVs. The Prius is an 83% gasoline and 17% electric car, based on its battery weight. One may also say it is 37% electric, since 20% of the total energy consumption is regained by the regenerative braking system (Maruo, 1997).

Honda's Insight differs from the Prius by using an in-line 10kW DC brushless motor combined with a 1.5-litre, three-cylinder engine, in a package which Honda calls 'integrated motor assist'. The Honda 'VV', is a hybrid passenger car powered by a 1-litre gasoline engine. A combination of refined aerodynamics, low weight and the hybrid power train will give the car near 3.0 litre/100 km fuel economy (AEA, June 1999).

Hybrid vehicle systems are still at an early stage of development. As yet, there has been no convergence of technologies onto one dominant system design. An equal number of series and parallel systems are under development. This reflects the trade off between improved fuel economy of parallel systems when compared to the potentially lower overall emissions which can be achieved by series designs. Generally, there seems to be a consensus that parallel hybrids will dominate the market initially followed by series designs.

VEHICLE APPLICATIONS

As the range and performance of hybrid vehicles is equivalent or better than current ICE counterparts, in principle, there exist no restrictions on the applications for which HEVs can be used. In practice, hybrid cars are being commercially developed first, with buses and other vehicles to follow.

VEHICLE AVAILABILITY

Hybrid vehicles are not yet commercially available in the UK. However, Toyota and Honda have announced that they will launch the Prius and Insight respectively in Europe in 2000.

Fuel

FUEL SUPPLY AND INFRASTRUCTURE ISSUES

The great advantage of hybrid vehicles is that they require no change in fuel or infrastructure. Future HEVs may very well be fuelled by alternative fuels, but the first

generation of commercially available hybrids are powered by petrol or diesel fuel. The advantages of HEVs i.e. higher fuel economy and reduced emissions, result from the fact that the fuel is used in a more efficient way.

SAFETY ISSUES

Petrol and diesel fuelled HEVs pose no significant safety considerations other than those associated with conventional petrol and diesel vehicles.

Environmental Impact

VEHICLE EMISSIONS

As shown in Charts B2–B9, all regulated emissions are significantly reduced for a petrol-hybrid passenger car as compared to a petrol ICE vehicle. The reductions are CO (40–77%), THC, (up to 67%) and NO_x (33–70%). No data is available regarding particulate emissions, but a reduction is expected. Moreover, the regulated emissions analysed show that a Prius already meets Euro 4 standards. Significant reductions for a hybrid-bus are also found.

FUEL CONSUMPTION AND LIFE-CYCLE EMISSIONS

The Prius reportedly achieves a fuel economy of 3.6 litres/100 km (78 mpg) on the Japanese 10–15 mode drive cycle. On a more challenging European drive cycle, the Prius is expected to achieve 4.7 litres/100 km (60 mpg).

Fuel consumption data shows that, for a Prius compared to an equivalent ICE vehicle, fuel economy is improved by around 30%. This improvement results in a significant reduction in vehicle CO_2 emissions, roughly in the order of 28% (see Charts B2–B9).

Research in the US has compared the fuel economy of hybrids with conventional cars. Using current and projected vehicle and component data, the study used the NREL's vehicle performance simulator ADVISOR to compare DI Diesel ICE vehicles with series and parallel hybrid versions using DI Diesel and Advanced Lead-Acid battery technology (Cuddy & Wipke, 1998).

The results from the study suggest that both hybrid versions are more fuel efficient than the conventional diesel vehicle. On urban drive cycles, the series and hybrid vehicles showed an improvement of 26% and 30% respectively. On combined urban and highway modes, the reductions were 18% and 24% respectively. This is comparable to the predicted fuel efficiency improvements of the Prius.

Market Acceptance

STANDARDS AND REGULATIONS

Given the trade off between improved fuel economy of parallel systems and lower overall emissions of series designs, legislation may play a crucial role in favouring one system over the other. More stringent the requirements for long zero-emission operation, reduce the overall fuel consumption and emission.

ECONOMIC ISSUES

Due to a significantly improved fuel economy, hybrid vehicles have reduced fuel costs (about 30% reduction predicted for Prius). However, the higher capital costs of hybrid vehicles result in an increase in the total lifetime costs compared to conventional vehicles.

DETR Leaf modelling shows that the life-time public and private costs are both increased. For the passenger car, the increase in public costs is around 50% and private costs are up by 22–37% before subsidies. However, with 50% Powershift funding, this is reduced to a 13% premium or less (a level similar to BEVs). Diesel hybrid buses also have increase private costs of 64–69% (0% Powershift) and 29-32% with 50% Powershift funding. As the vehicle cost is forecast to reduce over the next 5 years, private costs may be comparable with conventional vehicles by 2005. This will be assisted by economies of scale production if sales increase as predicted.

Initially, the price of the Prius in Japan was £11,000 (EVP, 1997). This compares with an ordinary 1.5 litre petrol car costing around £8250. However, it has been reported that Toyota are subsidising the Prius by around £20,000 per vehicle (Rupper, 1998). Therefore, it seems likely that hybrids cost significantly more than their conventional counterparts.

HEVs provide the potential for reduced operating costs offsetting the higher capital cost. This is illustrated by the decision of the Japanese company Heiwa who has announced that it will replace all 260 vehicles of its company fleet with the hybrid between now and 2001. This decision was based both on the Prius' (subsidised) forecourt price and a projected fuel saving of over £240,000 over a three year period (AEA, 1998).

MARKET POTENTIAL

If hybrids live up to the expectations raised, they will compete favourably with battery EVs that are currently being developed. In the first 30 days following the launch of the Prius, Toyota received over 3,500 orders, more than triple the original sales projection and, in Japan, over 30,000 units have been sold. Toyota currently produce 1,500 cars per month which exceeds the total annual number of BEVs sold within the whole of Europe. The Toyota Prius' second generation version, with enhanced motorway performance, is due in Europe in 2000.

In addition to the Prius, Toyota has announced it will launch two new hybrids by the end of 2000, a minivan and a sports utility vehicle. The minivan named the Estima, will be powered by a hybrid electric power-train including a 2.2 or 2.4-litre engine (AEA, 1999b).

The market for hybrids is predicted to expand rapidly from early 2000 and is being entered by both Honda and Nissan in addition to the vehicles launched by Toyota. For example, the Insight will be produced at a rate of 6,500 a year world-wide and will be available in Europe and the US early next year.

Hydrogen

The use of hydrogen as a vehicle fuel offers the following benefits:

- **ultra-low or zero regulated emissions at point of use;**
- **significantly reduced or zero life-cycle greenhouse gas emissions;**
- **equivalent performance to conventional vehicles;**
- **suitability for all vehicle categories.**
- **reduced noise levels**
- **emissions performance maintained for life of vehicle;**
- **no/simple catalyst required by hydrogen ICE vehicles.**

Hydrogen ICE technology has the following disadvantages:

- **undeveloped hydrogen fuel infrastructure;**
- **trade-off between performance and NOx emissions if a catalyst is not used;**
- **low fuel-cycle efficiency.**

Fuel cell vehicle technology has the following disadvantages:

- **undeveloped fuel infrastructure (on-board fuel as yet undecided);**
- **high cost of fuel cell production due to current state of technology;**
- **little convergence of fuel/vehicle design options;**
- **low vehicle availability.**

GENERAL CONCEPT – HYDROGEN ICE AND FUEL CELL VEHICLES

Hydrogen has the highest energy density and potentially the least environmental impact of all chemical fuels. The chemical potential energy of hydrogen can be released through either combustion to form water and small amounts of NO_x or in the presence of a catalyst to produce water.

In principle, renewable energy can be used to extract hydrogen from water with minimal emissions. The hydrogen can then be stored and transported to point of use. A renewable cycle would result in zero emissions being generated during fuel production.

Hydrogen gas can be used directly as a fuel in internal combustion engines. The gas can be stored on-board a vehicle in compressed or liquefied form and can be used in bi-fuel or dedicated gas engine vehicles. When burned in an internal combustion engine, water is left over as the residue. Though NO_x is produced in the engine combustion process, this can be controlled through the balancing of the air supply and/or through the use of a simple catalytic converter.

Hydrogen gas can also be used to power a fuel cell which converts chemical energy directly to electrical energy. In the most efficient configuration for vehicle applications, hydrogen and oxygen (from the air) are fed into a low temperature fuel cell (<100°C). The electricity produced is then used to power a conventional electric drive-train.

UK AND WORLD-WIDE EXPERIENCE – HYDROGEN ICEVS AND FUEL CELL VEHICLES

Hydrogen gas internal combustion engines have been successfully demonstrated around the world over the past two decades. BMW is now in the fifth generation of prototypes. At present there are two experimental cars running. One is providing a VIP shuttle service within the Munich airport using a robot-operated filling station. A series of 15 vehicles will be produced for the EXPO 2000 at Hanover. These cars will be equipped with bi-fuel engines and fuel cells as auxiliary power units instead of lead-acid batteries.

A hydrogen powered bus provided by MAN is in regular service within the Munich airport using the hydrogen filling station (which is available for public use). A limited number of technical showcase buses using hydrogen gas are operating in German cities (DaimlerChrysler).

Several hydrogen fuel cell vehicles have been successfully demonstrated around the world over the past two decades. Following a series of prototypes, DaimlerChrysler have collaborated with Ballard Power Systems and Ford to produce the Necar 4 fuel cell vehicle. This uses liquid hydrogen to provide energy to a fuel cell powered Mercedes-Benz 'A-Class' passenger car which has a range of around 400 km. The fuel cell manufacturers, Ballard Power Systems, have been quick to see the potential for clean transport technologies and are now world leaders in their field.

Ford have developed their own fuel cell car, the P2000. The vehicle is based on Ford's advanced lightweight research vehicle platform, and although slightly larger than a Mondeo with the capacity for five passengers, it weighs less than 1,520kg. The fuel cell stack was developed by Ballard and uses the same fuel cell technology as the Necar 4

(AEA, 1999a). Toyota, Nissan, Honda, Mazda and GM/Opel have all demonstrated prototype fuel cell vehicles

In North America, both the Chicago Transit Authority and the City of Vancouver operate three Ballard produced fuel cell buses. These use 200 kW fuel cell stacks and are fuelled by compressed hydrogen. DaimlerChrysler have built the Nebus which is a fuel cell version of a standard low-floor bus. Cylinders, mounted on the roof, contain 45,000 litres of compressed hydrogen at 300 bar, giving a vehicle range of 200 km.

DeNora from Italy have produced a fuel cell which will be used in a Neoplan bus (Germany) following trials with a bus in Brescia, Italy. The Bavarian government have also funded a 120 kW Siemens fuel cell for use in a MAN bus. Linde will supply the hydrogen required.

The UK company Zevco have developed the first fuel cell taxi. The company manufacture fuel cells based upon a design developed and patented by Elenco BV (Belgium) which Zevco bought in 1996. The company intend to mass produce fuel cells and will licence vehicle manufacture to produce vehicles using the technology it has developed. A Zevco utility vehicle is in operation in the City of Westminster, London.

In order to demonstrate the reality of zero life-cycle road transport, in California's Palm Desert Project, renewably produced hydrogen supplies a fleet of small fuel-cell utility vehicles for use by the local government staff travelling between office sites. The hydrogen fuel cell 'buggies' give a petrol equivalent of 2.16 litres/100km and take only 2 minutes to refuel.

Vehicles

VEHICLE TECHNOLOGY – HYDROGEN ICE

In principle, any spark-ignition ICE can accept hydrogen as a fuel with relatively minor modification. The 7-series BMW car is based on the advanced twelve-cylinder petrol engine with four overhead camshafts. The 750hL has a displacement of 5.4 litres and delivers around 150 kW (240 hp). The engine can be switched over to hydrogen while travelling. The air intake of the engine has been modified. An earlier 7-series model is also in operation, the 728hL, fitted with a six cylinder, 2.8 litres displacement engine developing 80kw (110 hp).

As the concept is bi-fuel based, the engine is not optimised for liquid hydrogen use. In the case of monofuel operation the engine performance could be optimised through higher combustion ratios and NO_x emissions reduced by incorporating alternative ignition and/or exhaust treatment techniques.

VEHICLE TECHNOLOGY – FUEL CELLS

Fuel cells are capable of high conversion efficiencies which compare favourably to the thermal efficiency for petrol and diesel engines. When the energy losses of electricity generation are taken into account, life-cycle fuel cell efficiencies can be considerably

higher than for BEV operation. In addition, the fuel cell engine is very efficient at low load providing even greater benefits on an urban drive cycle.

Mainstream automotive fuel cell development is focussed on the Proton Exchange Membrane Fuel Cell (PEMFC). The principal advantage of the solid-state PEMFC for transport applications is the ability of the fuel cell to operate at relatively low temperatures (80°C) which reduces start-up times. However, due to the current low volumes of production, the cost of PEMFC fuels cells remains high (current costs for Ballard PEMFC production are of the order of £2,500 per kW.)

Minority interests are demonstrating and developing phosphoric acid (PAFC) and alkaline (AFC) fuel cell systems. Unlike PEMFCs, AFCs are an established technology and are cheaper to manufacture. However, AFCs are CO_2 intolerant, which means that an on-board 'scrubber' must be fitted to the vehicle.

According to Ballard, for PEMFCs, 1.4 kW output per litre volume of fuel cell has been achieved. With this power output, the volume required for a passenger car fuel cell is only slightly larger than the volume required for an ICE. Even after the fuel systems, electric motor and drive-train are included, the volume required for a fuel cell system is still only slightly larger than the space taken up by conventional engine systems.

The Necar 4 is powered solely by a PEMFC. The fuel used is pure hydrogen. However, past and future models (Necar 3 and 5) have used methanol and an on-board reformer to generate hydrogen, so circumventing the need for a hydrogen fuel infrastructure. The Necar 3 has a range of 400 km on an 11-gallon tank of methanol and can be refuelled in minutes.

The Ford P2000 has been demonstrated using compressed hydrogen, but liquid hydrogen is planned to improve range, which is currently 160 km. The fuel cell system weighs 172kg, comprises three stacks containing 400 cells and the gasoline equivalent fuel economy on the combined cycle is 3.5 litres/100 km (AEA, 1999a).

Nissan is road testing a fuel cell vehicle which it says could be in commercial use in 2003. The vehicle uses a methanol reformer and also carries a lithium-ion battery pack. Tractive power is from a synchronous electric motor using the Neodymium permanent magnet technology, already deployed in the Altra BEV available in the US. Unlike the Necar 4, the battery pack is used for tractive power, something which DaimlerChrysler has worked hard to avoid in the interests of cost and weight saving. However, the Nissan prototype does make use of regenerative braking, something the Necar vehicles are unable to do.

Zevco have opted for the cheaper alkaline fuel cell which has potential in the short-term as a commercial fuel cell for vehicles. The company estimate that the cost of producing AFCs is currently around £2000 per kW. The Zevco taxi uses a small (5kW) stack to charge an on-board battery system. The hydrogen is stored in a gaseous form under pressure and can be refuelled in less than 10 minutes. The fuel cell size has been matched specifically for use with commercial vans, taxis and other urban use vehicles, but may not be suitable for buses or private cars.

VEHICLE APPLICATIONS – HYDROGEN ICE AND FUEL CELL VEHICLES

Hydrogen fuel can be used in any ICE vehicle type. There are no disadvantages in principle to acceleration, car performance, operating range, hill climbing capacity and overall vehicle operation in comparison to standard petrol and diesel operated vehicles.

In principle, fuel cells can be used in all vehicle types. In practice, if compressed hydrogen is used, current storage cylinders impose a weight and space penalty which may be unsuited to some vehicles. The first generation fuel cell vehicles are most likely to be passenger cars, light-duty vans, buses and specialist vehicles (e.g. airport tugs).

VEHICLE AVAILABILITY – HYDROGEN ICE AND FUEL CELL VEHICLES

At present there are only two (liquid hydrogen) ICE experimental cars running. A small series of 15 vehicles will be produced for the EXPO 2000 at Hanover. These cars will be equipped with bi-fuel engines and fuel cells as auxiliary power units instead of lead batteries.

At present no PEMFC vehicles are commercially available in the UK. However, PEMFC vehicles are highly likely to be available in the next few years. The DaimlerChrysler-Ford-Ballard partnership have repeatedly announced the aim to market a fuel cell car by 2004 (with Japanese companies quoting 2003). Further development of the fuel cell buses on trial is also taking place with commercial bus engine sales planned for 2002.

Fuel

FUEL CHARACTERISTICS AND STORAGE

Hydrogen gas is highly buoyant in air, non-toxic and combustible and releases a large amount of energy per unit mass (120 MJ/kg as compared to 42 MJ/kg for petrol). Used within an ICE, the combustion products of hydrogen are water vapour and small amounts of NO_x, due to the presence of atmospheric Nitrogen. Used within a fuel cell, the product is water vapour. The low temperature of operation means air can be used in place of pure oxygen. Hydrogen therefore offers itself as an ideal 'clean' fuel.

The use of hydrogen as a fuel is not new. 'Coal gas' or 'town gas', which is at least 50% hydrogen, has been used extensively throughout the industrial nations and preceded the use of natural gas in North America and Europe. At present, around 2% of the world's energy consumption is in the form of hydrogen for use in the chemical and other industries (Boyle, 1996). There is a lot of experience with hydrogen production, storage and distribution.

On-board storage of hydrogen gas has presented a technological challenge to vehicle design. Hydrogen's low density means that a very large fuel-tank could be required (about 800 times the volume of a conventional petrol tank at room temperature and pressure). The solution is to either compress or liquefy the gas to reduce its volume.

Currently compression is the most cost-effective solution, the gas being stored in cylinders at around 200 bar (though 300 bar is simple to achieve and 500 bar is possible). Cryogenic systems have been demonstrated which retain the low temperature required for hydrogen liquefaction (-253°C). This method was used by BMW in their early Series-7 test vehicles. Both methods require energy to compress or liquefy hydrogen gas. The energy required for liquefaction is much higher.

Another method of hydrogen storage is to use metal-hydrides. These alloys absorb hydrogen when under pressure, and incorporate it into the metal's structure. To release the gas, heat is applied and the pressure reduced. 7% of the hydride is hydrogen by mass, which is very close to energy densities of low-temp liquid hydrogen.

Recent research suggests that low temperature storage can also be achieved by cryo-adsorbtion onto the surface of modified carbon. At 77K and pressures of up to 60 atm, 4% of hydrogen by weight has been adsorbed. However, this new method remains under development and its cost-effectiveness has yet to be demonstrated . In addition, work on the use of carbon nanofibres has suggested possible storage densities of 30% w/w.

An alternative approach which avoids the storage problems, is to catalytically reform a hydrogen-rich fuel on-board the vehicle. In principle, any hydrogen bearing fuel such as petrol or methanol can be used, although simpler hydrocarbons are easier to reform. Due to its high hydrogen content and simple molecular structure, methanol is the preferred fuel used for on-board hydrogen production. This option has been developed by DaimlerChrysler for the Necar 3 and for the forthcoming Necar 5 due to be demonstrated in 2000. On-board reformers, however, result in an energy penalty and lead to a fuel cell vehicle which is not a true ZEV.

In 1999, Plug Power and Epyx Corporation demonstrated an integrated system on a test-bench comprising a fuel cell stack and multi-fuel processor which runs on petrol rather than methanol. The system achieved 40% efficiency at steady state, met ULEV criteria and is also expected to achieve up to 80 mpg (US gallon). However, at present, they remain at the development stage and costs are as yet unpredictable (AEA, 1999b).

Current automotive grade petrol contains too many components to reform. Sulphur, in particular, is deadly to the catalysts, such as those found in both the fuel processor and fuel cell stack. So the sulphur has to be removed, either on-board the vehicle, or in the refinery. This reinforces the trend towards very low sulphur (<50 ppm with a possible view to <10 ppm) which is already underway. This will increase energy consumption and CO_2 emissions from refineries and so reduces some of the benefits of using fuel cell vehicles.

Despite the work at Epyx and others, the general consensus seems to be that conventional petrol is unlikely to be used in fuel cell vehicles, and that the preference will be for some form of synthetic pseudo-petrol manufactured using gas-to-liquids technology. This would be homogeneous and sulphur-free, making it much easier to reform. However, it would also require a separate distribution infrastructure, reducing some of the benefits of a reformer based system (AEA, 1999a).

FUEL SUPPLY

The most widespread method for the commercial production of hydrogen is steam reforming of natural gas. Although other hydrocarbons can be used, methane is preferred as the ratio of hydrogen to carbon atoms is highest at 4:1. Processes for the 'gasification' of coal have been developed for large scale hydrogen gas production.

Biomass (plant material or organic waste) can be also used to produce syngas via the process of pyrolysis or gasification. This produces a gas which is composed of hydrogen and carbon monoxide. The hydrogen can be separated as required. Up to 60% of the material is converted to gaseous form with 10% left as residue.

An alternative to reforming is 'electrolysis'. Electrical energy can be used to 'split' water, and release hydrogen gas. This converts electrical energy into stored hydrogen, and provides a way of converting renewably generated electricity. It may also assist in 'smoothing' the electrical load on the grid, improving efficiency and reducing generating costs.

If on-board reformers are used, a sustainable and economic source of supply of the chosen fuel will have to be guaranteed. Specially formulated petrol, diesel or methanol are the most likely contenders, methanol can be readily derived from natural gas, petroleum gas or bio-mass.

INFRASTRUCTURE ISSUES

If hydrogen fuel is used, this would involve a high level of major engineering work to develop a completely new fuel infrastructure. To distribute the gas in its gaseous form, modified natural gas pipes could be used. An extensive hydrogen pipeline network has been effectively used by the chemical industry in Europe for many years.

Hydrogen fuelling stations are already publicly accessible in Hamburg and in Munich Airport. Depot based refuelling points provide the fuel cell buses with hydrogen in Chicago and Vancouver and there is a small hydrogen refuelling station in London for experimental fuel cell vehicles.

There have been a number of studies conducted into how a hydrogen fuelling network might be set up. Instead of installing a pure hydrogen infrastructure in the short term, use could be made of the existing natural gas network and small-scale reformers could be installed at fuelling stations to make hydrogen on-site. The use of energy feed-stocks such as natural gas, electricity or municipal solid waste used in conjunction with electrolysis or reformer technology can aid the development of 'cheap', 'local' hydrogen networks. The hydrogen could be stored in compressed cylinders like CNG and delivered to vehicles in the same way (AEA, 1999a).

Environmental Impact

VEHICLE EMISSIONS – HYDROGEN ICE

A hydrogen powered ICE vehicle is a low-emission vehicle. Of the regulated emissions, only NO_x is present. Levels are relatively low and can be effectively controlled using as catalyst. However, no data is available for the purposes of this report. The only other significant emission is water vapour.

VEHICLE EMISSIONS – FUEL CELL

A hydrogen powered fuel cell vehicle is a true zero-emission vehicle. If methanol fuel is used as the hydrogen carrier, gaseous emissions are produced during the reforming process. Therefore, the first fuel cell vehicle is likely to be a ULEV rather than a ZEV. However, the only reliable data available relates to the use of pure hydrogen fuel cell cars (the Necar 4 and the P2000). Therefore, only life-time global emission data is used, and the other vehicle emissions are taken as zero.

FUEL CONSUMPTION AND LIFE-CYCLE EMISSIONS – HYDROGEN ICE

No information is currently available regarding the fuel consumption of hydrogen ICE vehicles.

Although vehicle CO_2 emissions are zero, greenhouse gases may be emitted during production of the hydrogen fuel. Therefore, life-cycle CO_2 and methane emissions must be considered to ascertain the greenhouse gas emission resulting from fuel cell vehicle use.

FUEL CONSUMPTION AND LIFE-CYCLE EMISSIONS – FUEL CELL

Fuel economy is greatly improved through the use of fuel cell vehicles. This is primarily through the high efficiency of the drive-train. For example, the fuel economy of the Necar 4 using pure hydrogen is 1.07 MJ/km while the methanol version is predicted to have a fuel economy of 1.70 MJ/km (AEA, 1999a). The larger P2000 compressed hydrogen version is reported to have a fuel use of 1.13 MJ/km.

Although vehicle CO_2 emissions are zero, greenhouse gases may be emitted during production of the hydrogen fuel. Therefore, life-time CO_2 and methane emissions must be considered to ascertain the greenhouse gas emissions resulting from fuel cell vehicle use. However, even when production emissions are taken into account, a FCV passenger car of the P2000 size reduces greenhouse gas emissions by around 50% (see Charts B2–B9).

SAFETY ISSUES

Hydrogen is not necessarily a more dangerous fuel than petrol or other flammable fuels and may be safer. In the event of a fuel spill, although hydrogen is more inflammable, a petrol fire will last far longer. Hydrogen fires produce no toxic fumes, unlike conventional fuels. Also, hydrogen rises away from the spill site, unlike liquid fuels which remain in the spill area. However, the hydrogen molecule can make some metals more brittle.

For equivalent energy and volume storage, hydrogen has the least explosive potential when compared to methane and petrol. However, it does have the highest combustion heat and explosive potential by mass.

Methanol can be used for on-board reforming to hydrogen, but it is toxic and requires careful handling. It is also hydrophilic, so care needs to be taken if it is used near water supplies. Furthermore, methanol can corrode some materials used for conventional dispenser hoses.

Market Acceptance

STANDARDS AND REGULATIONS

Initiatives are taking place within the International Standards Organisation (ISO) under its working group TC1 97, which deals with hydrogen as a fuel, and in Europe as a collaborative venture under the acronym EIHP – European Integrated Hydrogen Project. These are aiming to address the issues associated with engineering risk and acceptability of hydrogen, and have many of the larger players on board e.g. BMW, DaimlerChrysler, Opel, Gaz de France, Air Liquide, and the German standards organisation TUV. All of this effort suggests that there is movement in the direction of hydrogen standards and regulations (AEA, 1999a).

ECONOMIC ISSUES

The analysis conducted by DETR shows that fuel cell vehicles are currently very expensive on a private and public cost basis. Private costs are increased by a factor of 5 for a fuel cell car (3.5 with 50% Powershift funding) and public costs are increased by a factor of 7. This is primarily due to the high capital cost of fuel cell technology. However, vehicle and engine costs are predicted to fall rapidly with mass production.

Data from Hamburg suggests that fuelling costs for the van running at present on hydrogen are about 50% more than for an equivalent van using diesel. Using a fuel cell vehicle instead of a conventional ICE would involve a greater capital cost, but the running cost could drop significantly – perhaps below diesel – because of the much higher efficiency (AEA, 1999a).

Although it is impossible to make definitive statements about future FCV economics because the technology is still evolving, it is instructive to compare a number of cost

scenarios. Analysis by Lillie in Section C and other sources indicate that (over the next 5 years):

- FCVs will continue to have higher capital costs than conventional vehicles.
- FCVs will have lower maintenance costs than conventional vehicles.
- Life-time private and public costs will remain relatively high.
- Fuel cell engines will have same production costs as conventional engines when production volume reaches 250,000 units per year.

MARKET POTENTIAL

DaimlerChrysler and Ford have formed partnerships with Ballard Power Systems in Canada who are world leaders in fuel cell technology. The companies have repeatedly announced the aim to market a fuel cell car by 2004.

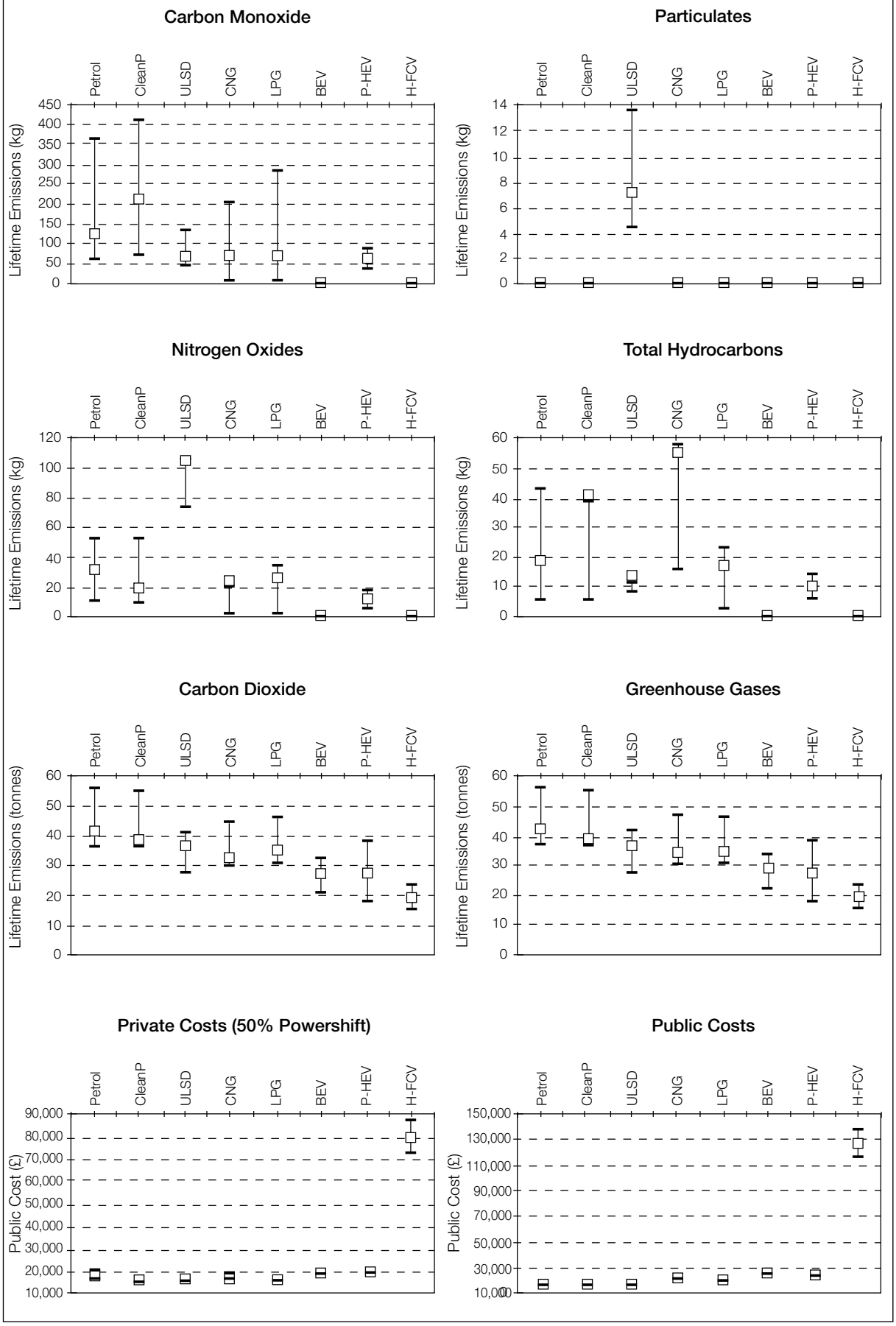
Further development of the fuel cell buses on trial is also taking place. Daimler Chrysler has now stated that its Mark IV engine will go into commercial production in 2002. Toyota, Honda and Nissan have announced commercial launches in 2003 and GM and Ford have also announced commercial launches in 2004.

If costs of producing fuel cells can be reduced and there is agreement about which fuel should be used, there is a very large potential for FCVs. Given that most of the major car manufacturers are developing fuel cell vehicles, there is a good chance that significant numbers may make it to the market-place beginning in 2004.

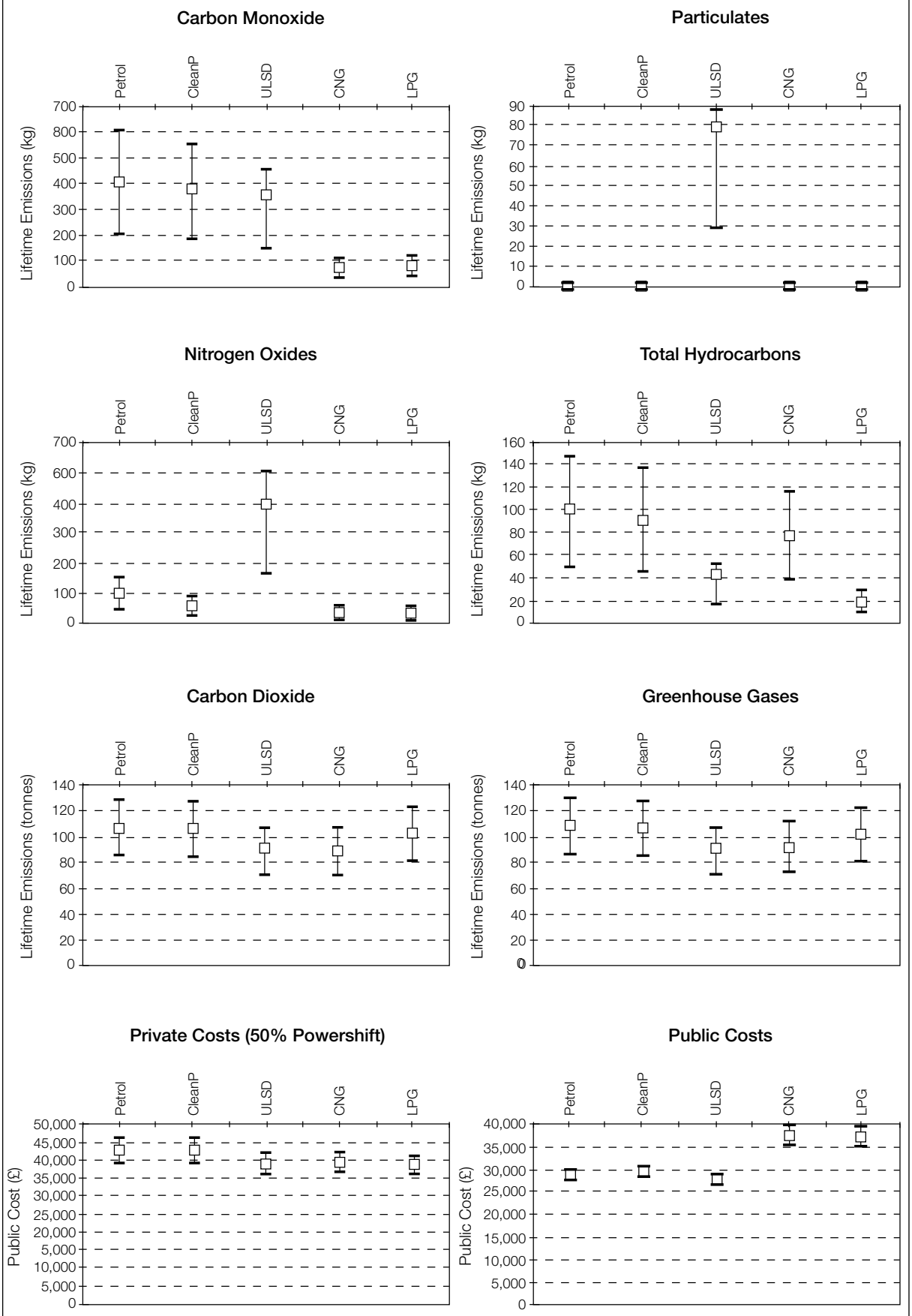
Additional Comments

Some analysts who consider hydrogen as a viable future vehicle fuel see the use of both natural gas and electric drive-train vehicles as intermediate steps in the transition to hydrogen fuelled vehicles. This is because handling and use of natural gas shows similarities with hydrogen and the use of current electric vehicles provides a development base for future fuel cell drive-trains (IEA, 1999).

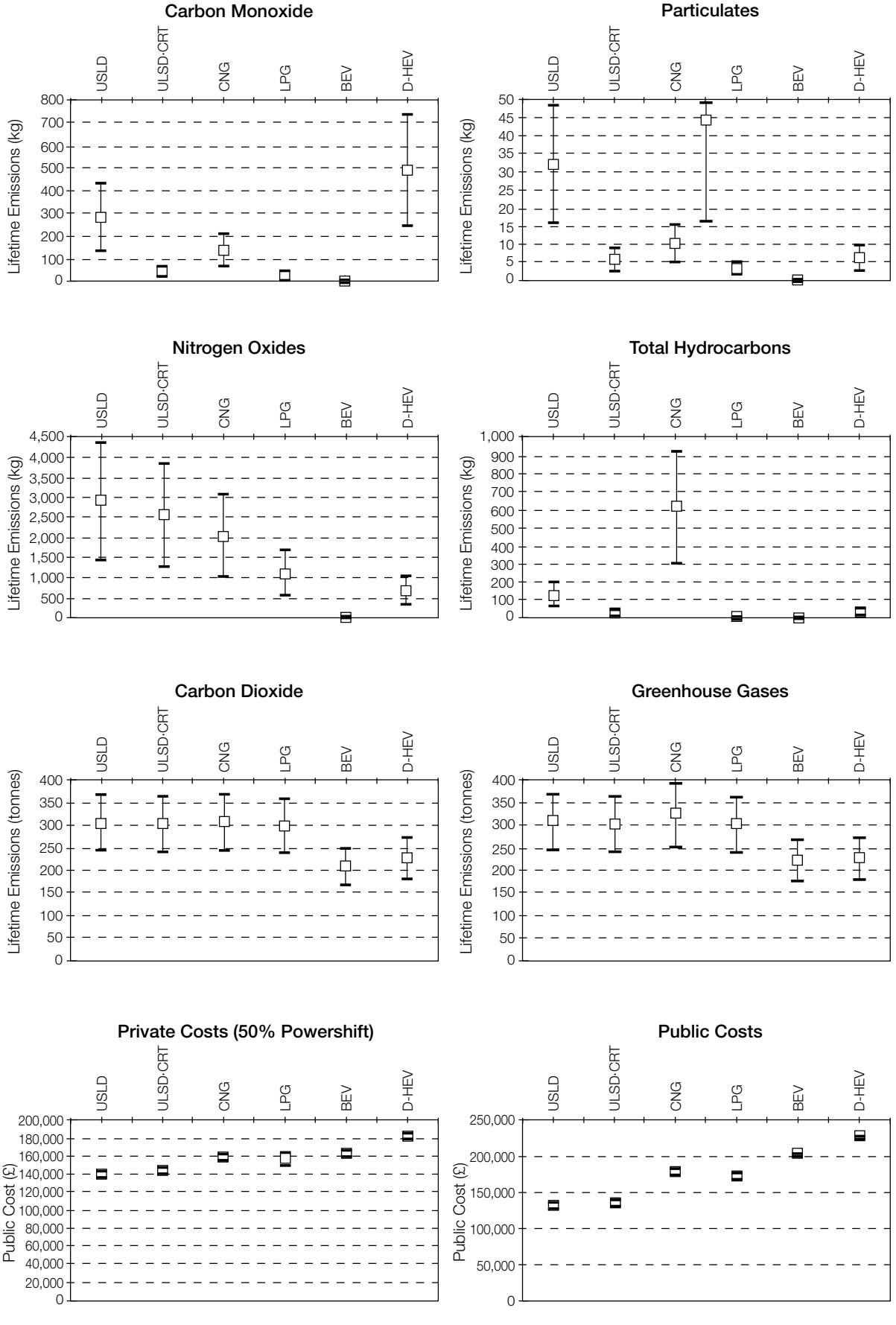
Charts B2–B9: Car: Year 2000 – Life-time Emissions and Costs



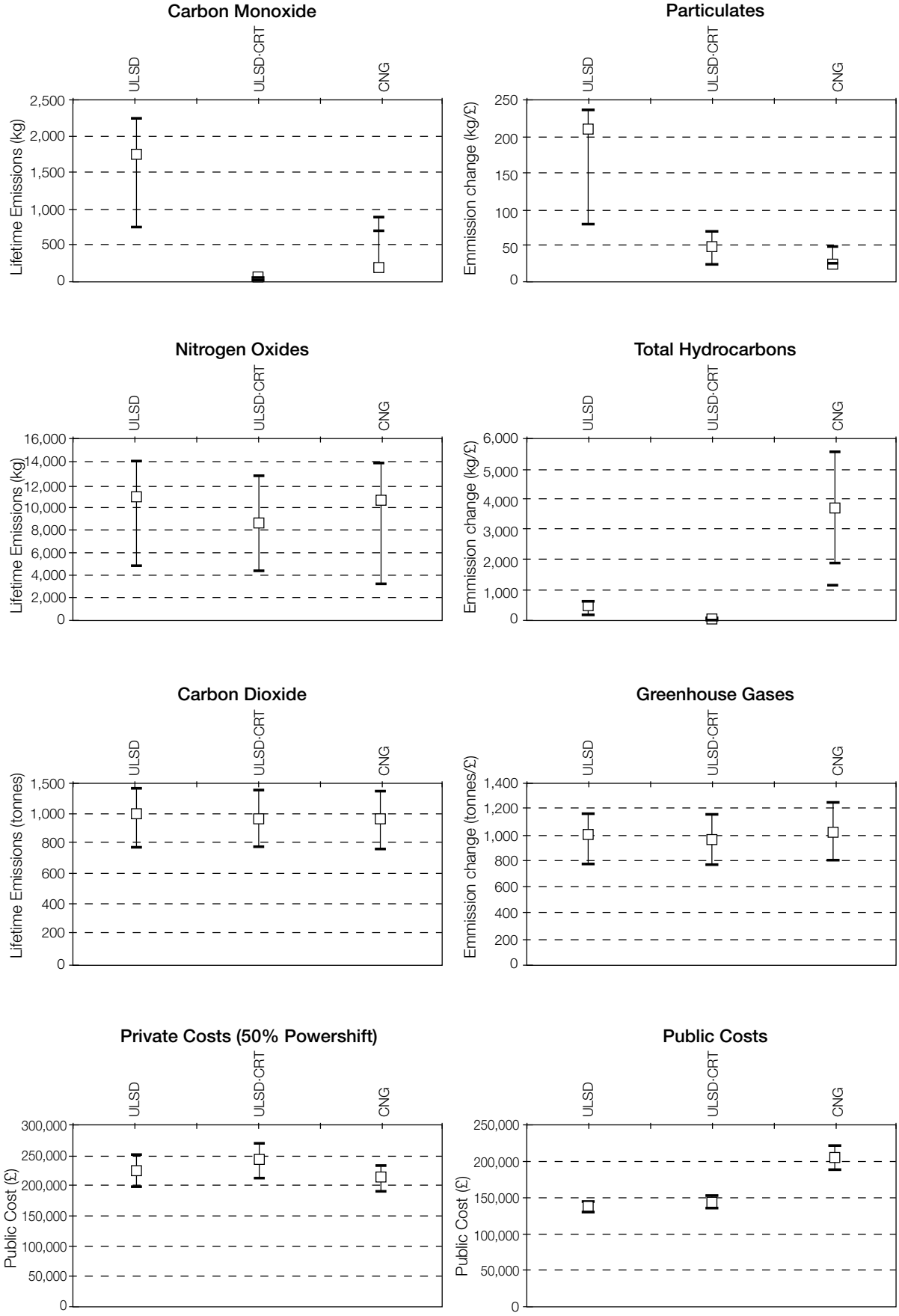
Charts B10–B17: **LGV: Year 2000 – Life-time Emissions and Costs**



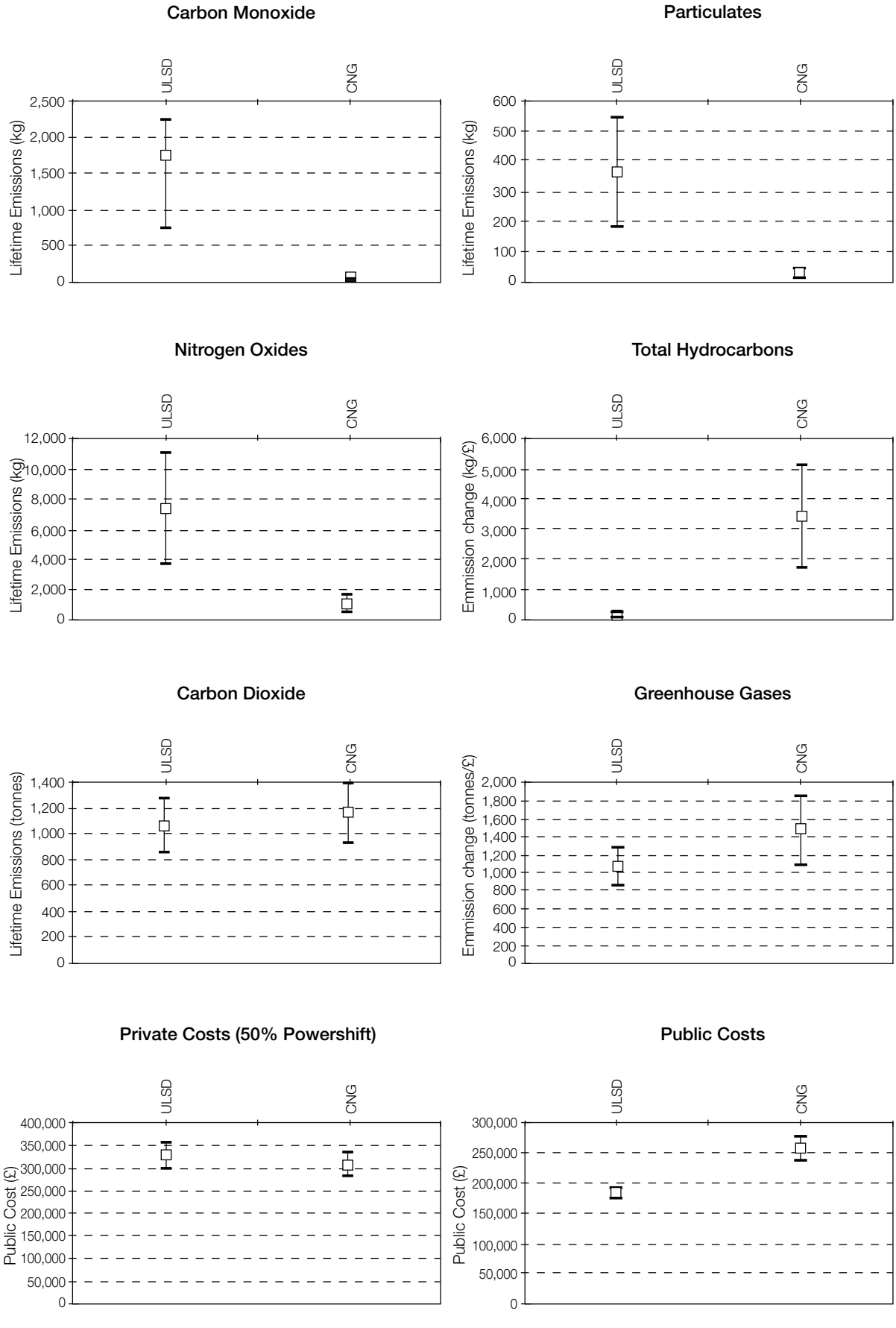
Charts B18–B25: **Bus: Year 2000 – Life-time Emissions and Costs**



Charts B26–B33: **Rigid: Year 2000 – Life-time Emissions and Costs**



Charts B34–B41: **Artic: Year 2000 – Life-time Emissions and Costs**



SECTION C:

Comparative Analysis of Cleaner Fuels and Vehicles

Emissions and Costs Associated with Cleaner Fuels and Vehicles – Present

Prepared for the Cleaner Vehicles Task Force Alternative Fuels Group by Ken Lillie of *Energy Technology Services*.

This section examines the use of alternative fuels, vehicle exhaust emissions and fuel economy for the present day and the year 2005. Five typical vehicle types are considered – passenger car (and light van), panel van, single deck bus, rigid truck (17t) and articulated truck (38/40t). For each type the alternative fuels/energy sources of LPG, CNG/LNG, Electric/Hybrid Electric and Fuel Cell are compared with conventional petrol and diesel fuels

In each case, the vehicle emissions and cost implications are considered, to provide the basis for a cost/effectiveness analysis. Whilst alternative fuels and technologies can provide emission and fuel economy benefits, the extent of these benefits depend on the fuel used and the vehicle application.

This section serves to inform the debate on:

- if the ongoing improvements in emission which are being developed for conventional fuelled vehicles (petrol/diesel) will be sufficient to satisfy the demands of society in the future;

- and which alternative fuels can best meet the combined demands of:
  - exhaust emission and the lifecycle emissions reductions;
  - vehicle purchase costs (e.g. fuel, maintenance and residual value);
  - customer desires for performance, product appeal, style.

ACKNOWLEDGEMENTS

The following organisations and individuals have contributed data used in the report. The views expressed in the report are a distillation of many opinions and are not attributable, necessarily, to any one person or organisation.

Consultation Document respondents: EA Technology, LPG Association, NGV Association, Imperial College

Direct discussions with: Millbrook Proving Ground (Lawson, Eastlake), Ricardo (Andersson, Thomas, Thring, Garrett, Whelan), MIRA (Callow, Charters), BP Amoco (Armstrong, Rinker), Cosworth (Stodart), BMW (Toulmin, Strobl), Walsall Borough Council (Morgan), Iveco Ford (Moore), Volvo Bus (Wickens)

Comments on draft from: DETR (Gaynor), Freight Transport Assoc. (Day), Ford Motor Co. (Whitehead), Royal Mail (Nota)

Alternative Energy/Fuels – Present Day

This section details the measured exhaust emissions data for a range of vehicle sizes and types using various alternative fuels and energy sources, as follows:

Vehicle types:

- Car.
- Light van.
- Panel van.
- Bus 12m.
- Rigid truck 17t.
- Articulated truck.

Fuels

- Petrol and clean petrol.
- Diesel and clean diesel.
- LPG – bifuel and dedicated.
- CNG/LNG bifuelled and dedicated.
- Electric – Battery and hybrid.
- Fuel cell.

The data is presented in **Tables E3–E7**, one table for each vehicle type, each table listing all of the fuel alternatives. As is to be expected, not all combinations of both types are available, reflecting the relatively immature state of the alternative fuels industry.

DISCUSSION OF RESULTS

Passenger car/car derived van (see Table E1)

The passenger car/car derived van data taken from the Vauxhall Combo tests at Millbrook has a high validity, covering 4 different fuels used on 4 similar vehicles, all OE build. This shows the clear benefit of LPG, with emission levels below conventional equivalent petrol. Levels are also below the 2000 Euro Stage 3 legislation, although it must be remembered that Stage 3 cannot be directly compared because the drive cycle now includes the emissions from the moment of engine start-up. NG also has good results except for the effect of methane emission in the hydrocarbons. These are both bi-fuel vehicles and so would be improved further if the engine control and exhaust after- treatment were optimised for a single fuel.

The dedicated CNG fuelled Honda passenger car, although not tested by an identifiable test organisation, shows the benefits of optimisation for a single fuel. This car is close to meeting EURO Stage 4.

The best performer is the Battery Electric, however emissions from energy generation and distribution need to be included in the overall environmental assessment.

The Hybrid Electric Toyota 'Prius', which although not directly comparable with other alternatives, does give emissions well below even the year 2005 Euro 4 legislation. Care has been taken in the selection of this data to ensure that the battery energy does not contribute to, or make use of, the net energy used in the drive cycle. This is also a first design, and therefore it would be reasonable to expect further improvements. Fuel economy improvements are also significant, and are estimated to be approximately 30% below a conventional vehicle.

The 'City' petrol emissions for CO is slightly worse, while THC+NO_x slightly better than standard unleaded petrol. However this cleaner fuel will be important to support exhaust aftertreatment systems that are being developed for future application.

Panel van (see Table E2)

Unlike the car/light van data, it was not possible to obtain data that originates from the similar vehicles tested together in a back-to-back test. An attempt has been made to provide comparative results by keeping to the same vehicle type.

The data shows a significant improvement for LPG and CNG/LNG over the conventional equivalents. The emissions are well below the 2005 EURO 4 standard.

No Battery or Hybrid Electric data is available for direct comparison. The most relevant data, when available, will be from the PSA Peugeot-Citroen 'Berlingo' hybrid electric van being developed as an EC funded project.

Bus – 12 m. 44 passenger (see Table E3)

In this sector diesel, dedicated LPG, dedicated CNG, electric and hybrid vehicles have been identified. Data is presented from comparative tests taken at Millbrook over simulated London bus test cycles on diesel, LPG and CNG which show, as well as the expected improvements over EURO 2 diesel for LPG and CNG, the clear benefits of both 'clean diesel' with a CRT particle trap and hybrid-electric technology. The CNG version has high THC due to methane.

Rigid Truck – 17t (see Table E6)
Only diesel and dedicated CNG vehicles have been identified in this vehicle sector. The data presented originates from 3 similar refuse collection vehicles tested together with 3 comparative fuels – diesel to BSEN 590, ultra low sulphur diesel and CNG. Measurements were made on the completed vehicles over typical drive cycles for the stop/start duties of this type of vehicle.

Large improvements over BSEN 590 diesel can be seen for ULS diesel, with further, much smaller, improvements for CNG in particle emissions. The large THC increase for the CNG vehicle is the result of methane.

Articulated Truck – 38/40t (see Table E7)
As with the 17t vehicle sector above, reliable data exists only for diesel and dedicated CNG vehicles. Two comparative sets of test data are available for two vehicles, one for each fuel, tested using typical heavy duty truck drive cycles. The two vehicles used were not identical, but were of comparable size.

Apart from methane emissions, the test data shows very large reductions for CNG compared to ULS diesel.

Emissions and Costs Associated with Cleaner Fuels and Vehicles – Future

Predictions of Alternative fuels in 2005

This section discusses the likely position in automotive technology and manufacture for the year 2005 in the areas of engine and powertrain, fuels, emissions, fuel economy and costs of manufacture and use.

ASSUMPTIONS

The predictions are based on opinions received from across the automotive industry in UK, namely vehicle manufacturers and suppliers, vehicle design consultants, vehicle test organisations and fuel suppliers. These opinions have not concentrated solely on the trends in UK, but also reflect world-wide trends

For each case considered below, an estimate has been made of the potential to develop volume production.

No account in cost estimates is made for vehicle purchase cost support from Powershift, nor any other possible vehicle purchase cost incentives.

EURO Stage 4 will be the required test cycle.

PASSENGER CAR and CAR DERIVED VAN

PETROL

Technologies

Average engine sizes slightly reduced to 1.5 litre for mid-range saloon. GDI stratified charge widely available to improve fuel economy. Pre-heat catalyst is unlikely, better favoured are close-coupled catalysts with EGR and secondary air inlet. Exhaust after-treatment well advanced, development of lean NO_x traps continues but not available in full volume.

Sulphur content limit of the fuel will be mandated to 50 ppm, however vehicle manufacturers believe that <10ppm should be the aim to support effective exhaust after-treatment systems.

Intense efforts on fuel economy to move towards the ACEA target of 140 gm/km by 2008, but much will have to be provided by vehicle body weight reduction.

Emissions

Euro 4 applies, some vehicles will be better in order to make environmental statement. Fuel consumption improved by 10–15%.

Vehicle Costs

Small purchase cost increase in real terms of about 3%. Service costs reduced by £200–£300, with extended intervals of up to 15,000 miles and 'intelligent' service notification. This implies a reduction of about 30%.

DIESEL

Technologies

Average engine sizes down to 1.8 litre and engine weight reduced by 10% to contribute to fuel economy. Direct injection with 'shaped' injection. $DeNO_x$ close coupled catalyst. Exhaust after-treatment well advanced with particulate traps into production. These will allow the particulate limits to be met with ease.

Smaller, lighter vehicles will be able to implement less expensive exhaust after-treatment systems. As with petrol, intense efforts on fuel economy.

Emissions

Major problem for heavier vehicles to meet Euro 4 if a small engine is used.

Sulphur content limit of the fuel will be mandated to 50 ppm, however vehicle manufacturers believe that <10ppm should be the aim to support effective exhaust after-treatment systems.

Small diesel engines will lead the efforts on fuel consumption. 15% reduction in fuel consumption likely from diesel and maintains the same relationship with petrol.

Vehicle Costs

Small increase in real terms about 3% and still about £1k more than petrol. Service costs reduced as with petrol.

LPG

Technologies

Dedicated engine and exhaust catalyst available, although bi-fuel systems with exhaust catalysts will dominate. Similar engine management as petrol. Sub-zero temperature cold start problem eased by pumped liquid systems.

For gaseous fuels, concentration on the passenger car and van sectors, because of fuel infrastructure availability and easier installation in smaller vehicles.

Emissions: Meets Euro 4 and is also better than petrol/diesel for particulates and NO_x. Energy consumption is similar to petrol on an energy basis.

Vehicle Costs: Additional cost above petrol of £1000, assuming volume levels, of about 1–2% of vehicle sales, mostly for fleet applications. All main OEM suppliers offer versions.
Long service interval, as with petrol, at about 25,000 miles.
Similar maintenance cost per km to petrol equivalent.

CNG

Technologies: Dedicated engine and exhaust catalyst available, although bi-fuel systems with exhaust catalysts will dominate. Catalyst optimised for methane. Similar engine management as petrol. Larger capacity engine to counter lower power, torque and fuel tank weight.

Emissions: Meets Euro 4, except for methane emission which remains a legislative difficulty. The cost of methane removal will be a major barrier to application, requiring an expensive catalyst with a high level of precious metal loading.

Ozone forming emissions substantially lower than petrol, diesel and LPG. Energy consumption less than equivalent petrol and LPG with 20% less tailpipe CO_2 emissions.

Vehicle Costs: Additional cost above petrol of £1500, volume levels less certain than LPG because fuel supply infrastructure less well established. Development and unit costs of methane catalyst also contribute to the vehicle cost.
Long service interval, as with petrol, at about 25,000 miles.
Similar maintenance cost per km to petrol equivalent.

BATTERY ELECTRIC

Technologies: 45kW pm motor and 20kWh Nickel Metal Hydride battery. Marketing target to reach 160km range between recharging and provide fast recharge capability.

Emissions: Zero at point of use but need to estimate electrical power source emissions. Overall likely to be half total pollutant emission of petrol, depending on power station line-up.

Vehicle Costs: Additional cost over petrol of £7,000 due to battery price, small production quantities and only a niche market product. Cost of battery replacement is major factor otherwise low maintenance because of small number of moving parts.

HYBRID ELECTRIC

Technologies: Many configurations are possible. Most likely is the 'mild' hybrid with a 20kW (inst.) pm electric motor in parallel with small 1 litre engine to aid acceleration and to allow fast start from engine off at idle. Nickel Metal Hydride battery size 2kWh. Engine most likely petrol, especially on Japanese vehicles, but could be diesel.

Emissions: Emissions less half that of Euro 4, with potential to reach CARB SULEV. Fuel consumption half that of equivalent petrol (3l/100km) without loss of performance.

Vehicle Costs: Additional cost over petrol of £6,000. Service and maintenance similar to petrol. Strong marketing emphasis on 'clean' image and high technology to support high selling price. Has the benefit over gaseous fuels of using the existing fuel infrastructure.

FUEL CELL

Technologies: Solid polymer with hydrogen fuel on-board, 50kW power output. Electric drive similar to battery electric and 'buffer' battery required for start up and acceleration. Methanol Reformer fuelled versions under development but not likely to be available by this time.

Emissions: No noxious gases for hydrogen fuelled version but need to consider emissions from hydrogen production and storage. These emissions will depend on fuel source and processing used. Reforming of natural gas is most likely in the short term with use of renewable electricity or electrolysis of water a possibility in long term.

Vehicle Costs: True volume manufacture will not be reached, therefore realistic costs cannot be provided. Future maintenance costs are uncertain.

PANEL VAN (<3500kg)

PETROL

Technologies: Power train technology closely related to passenger car (see above)

Emissions: Comments similar to passenger car

Vehicle Costs: Comments similar to passenger car

DIESEL

Technologies: Power train technology closely related to passenger car (see above)

Emissions: Comments similar to passenger car. Problem of small engine in heavy vehicle is more severe and will heighten the conflict between CO_2 and emissions.

Vehicle Costs: Comments similar to passenger car

LPG

Technologies: Power train technology closely related to passenger car (see above.) Potential for dedicated engine to meet optimum fuel saving.

Emissions Similar statement as passenger car.

Vehicle Costs Comments similar to passenger car Good market opportunity for local delivery vehicles with lower fuel cost. Problem of tank location is easier to solve than in the passenger car. Strong emphasis on fuel cost saving

CNG

Emissions Similar case as LPG, but CNG offers lower emissions except for methane and vehicle costs.

Vehicle Costs Higher vehicle cost due to tank and payload effect. Both LPG and CNG are likely to be offered as OE. Cost comparison with petrol similar as for passenger car.

BATTERY ELECTRIC Potential niche markets developing by year 2005.

HYBRID ELECTRIC Potential niche markets developing by year 2005.

FUEL CELL Potential niche markets developing by year 2005.

BUS 12m 44 SEAT SINGLE DECK

PETROL No vehicles likely in this sector

DIESEL

Technologies. 160kW DI with common rail injection and variable swirl. Close coupled active deNO_x exhaust after-treatment with particulate trap/filter and EGR.

Emissions. Meets Euro 4. Unlikely that vehicle based certification will be in place. Fuel consumption increase by 2–3%.

Vehicle Costs Increase of about £1500 to £2000 – cost of emissions equipment. Maintenance costs not likely to change from today.

LPG

Technologies. 160kW dedicated engine and exhaust catalyst available. Similar engine management as petrol. Sub-zero temperature cold start problem eased by pumped liquid systems.

Emissions. Large reduction from legislation, less than 10% of EURO 4 is possible. Most noticeable benefit is for particulates which can be lower than diesel equivalent. CO_2 emission 5% less than diesel

Vehicle Costs Additional cost of £10k above diesel, but costs could fall rapidly if world markets develop. Maintenance cost per vehicle km expected to be similar to diesel.

CNG

Technologies 160kW dedicated engine and exhaust catalyst. Lean burn direct injection and closed loop electronic injection.

Emissions Large reduction from legislation, less than 10% of EURO 4 is possible. As with LPG noticeable benefit for particulates which can be lower than diesel equivalent. Methane emissions will be a major issue in Europe, where they are included in THC measurement. CO_2 emission similar to diesel

Vehicle Costs Additional cost of £15k above diesel, but costs could fall rapidly if world markets develop. Major issue is whether lightweight tanks will be developed for volume manufacture. Maintenance cost per vehicle km expected to be similar to diesel, but the maintenance cost of refuelling station is not included.

BATTERY ELECTRIC

Technologies 100kW pm motor and 50kWh Nickel Metal Hydride battery. Fast recharge capability is essential to allow opportunity charging at turn-around points on the route. Move towards brushless dc and ac motor drive systems.

Emissions Zero at exhaust, need to estimate electrical power source emissions. Overall likely to be half total emission of diesel, depending on power station line-up.

Vehicle Costs Additional cost over conventional of £20k. Range limitation may not be an issue, especially for routes involving mostly city use. Chance to recover vehicle costs from fuel saving are not high, unless application is one where diesel fuel tax rebate does not apply. Maintenance cost (excluding battery costs) per vehicle km expected to be 50% lower than diesel.

HYBRID ELECTRIC

Technologies Either parallel or series power train systems are possible, the technology is too immature to be certain. Opportunity will be taken to downsize the combustion engine to meet only cruise power and allow the cheaper, higher volume engines from the passenger car market to be used.

Emissions Likely to be half of an equivalent conventional fuel, with the opportunity to run on electric only in sensitive areas.

Vehicle Costs Additional cost over conventional of £15k.
Maintenance cost per vehicle km expected to be similar to diesel.

FUEL CELL

Technologies Solid polymer with hydrogen fuel on-board, up to 200kW power output. Electric drive similar to battery electric and 'buffer' battery required for start up and acceleration.

Emissions No noxious gases but need to consider emissions from hydrogen production and storage.

Vehicle Costs This product is receiving most of the attention from the fuel cell industry, but it is likely that true volume manufacture will not be reached (though some fuel cell engine sales are predicted to begin in 2002), therefore realistic costs cannot be provided.

RIGID TRUCK – 17t

PETROL No vehicles likely in this sector

DIESEL

Technologies. Widespread use of continuous regenerative trap and exhaust gas recirculation systems in exhaust after treatment. 'Clean' fuels (sulphur below 10ppm) likely to be available but not mandated. NO_x catalyst systems not likely to be well developed.

Emissions. Meets Euro 4. Fuel consumption increase by 2–3%.

Vehicle Costs Increase of about £1500 to £2,000 for the cost of emissions equipment.

LPG Significant volumes unlikely in this sector by 2005

CNG

Technologies Development of low weight tank and dedicated engine with methane catalyst. For average truck the location of tank is easiest of all vehicle sectors. Likely to add an extra 0.8 to 1.2 tonne weight, depending on tank technology between steel and composite. Estimate of range limitation is 300km. and weight penalty of 750kg.

Emissions Most attention on fuel economy and cost relative to clean diesel. Emissions can easily meet EURO 4, but methane question will still be a problem

Vehicle Costs Likely that engine will be cheaper than diesel but cost of fuel tank will add up to £10k to vehicle cost.

BATTERY ELECTRIC No vehicles likely in this sector

HYBRID ELECTRIC No vehicles likely in this sector by 2005.

FUEL CELL No vehicles likely in this sector by 2005

ARTICULATED TRUCK – 38/40 t

PETROL No vehicles likely in this sector

DIESEL

Technologies 250kW DI with common rail injection and variable swirl. Close coupled active deNO_x exhaust after-treatment with particulate trap or filter and EGR.

Emissions Fuel consumption increase by 2–3%.

Vehicle Costs Increase of about £1500 to £2,000 for the cost of emissions equipment.

LPG No vehicles likely in this sector by 2005

CNG

Technologies	Similar comments to Rigid Truck.
Emissions	Will be used to develop the Environmentally Enhanced vehicle.
Vehicle Costs	About £17k per vehicle. Range limitation estimated at 400km. and weight penalty 1000kg.

BATTERY ELECTRIC No vehicles likely in this sector

HYBRID ELECTRIC No vehicles likely in this sector

FUEL CELL No vehicles likely in this sector

Alternative Energy/Fuels – Discussion

Good sources of comparative data for the exhaust emissions of similar vehicles fitted running on different types of fuel are available today and this has aided the study. However, such high quality data is not widely available, indeed, often there is only one single source involving one test on one vehicle type, for a number of alternative fuels. It will be important to obtain further data to support the validation as more products are introduced.

The study shows that significant emission improvements are gained from the use of 'clean diesel' with particulate traps. Moreover, after-treatment systems are likely to be required if diesel technology is to achieve Euro 4. There are also clear, measurable advantages to exhaust gas and particulate emissions reduction from the use of LPG and CNG together with fuel cost benefits resulting from the duty taxation differentials. However, these alternatives are predicted to add cost to the vehicle, certainly in the time frame up to 2005.

New, gaseous fuelled (and petrol) vehicles will be required from 2000, to fit On-Board Diagnostic systems to record any emission control malfunction. This is three years ahead of the similar requirement for diesel fuelled vehicles and will provide an additional barrier to development of gaseous fuel markets.

CNG vehicles hydrocarbon emissions contain over 80% methane, especially in the case of bi-fuel conversions where the catalyst has not been optimised for this gas. Because the Euro 3 legislation has a limit for total hydrocarbon emissions (unlike USA which has a limits for non-methane organic gases), creates an additional cost barrier for methane catalysts which is likely to inhibit market development.

Most attention in CNG is concentrated in the heavy engine sector, with the cross-over to LPG occurring at the panel van sector where one sees both fuels being developed.

Battery electric is seen as a niche market product because of the combination of range limitation and high cost. In terms of tail-pipe exhaust emissions, however, it is obviously the clear leader.

For all of the alternatives it is important to estimate the emissions and costs of fuel and energy generation, distribution and storage before it is used in the vehicle. This is particularly important for battery electric vehicles and methanol and hydrogen fuel cell vehicles.

Hybrid electric is a general term for an area of technology covering a very wide range of types of vehicles. These range from a battery powered vehicle with a 'range extender' series connected generator to a system which is a conventional combustion engine with a small, parallel connected motor to give some engine support – and all variants in between. This technology is likely to be applied to the car and bus sectors.

The essential benefit is hybrid electric vehicles in exhaust emission (compared to petrol or diesel) as is the case for LPG and CNG, but without the cost of developing the fuelling infrastructure and inconvenience to the user. However the vehicle on-cost is higher than LPG and CNG.

Fuel cell technology is still immature. Therefore it is difficult to collect good emissions data and make reasonable predictions for the future. It has the potential to provide very low emissions with high efficiency of fuel use. In the case of hydrogen fuel, where the hydrogen is generated from renewable energy sources, the total life cycle emissions are effectively zero without further range limitations on vehicle use.

Cost-Effectiveness Analysis of Cleaner Fuels and Vehicles

LEAF – Lifetime Evaluation of Alternative Fuels

Analysis by Joshua McCallum (DETR)

OVERVIEW

The LEAF model assesses the total and relative costs and emissions from alternative fuels in various vehicle types. The work was commissioned by the Alternative Fuels Group of the Cleaner Vehicles Task Force (CVTF).

The model compares, as much as possible, only equivalent vehicles. An equivalent vehicle can be defined as ones between which a consumer is likely to choose. Therefore, a 1.4l petrol hatchback is comparable to a 1.4l CNG hatchback, but is not comparable to a 2.5l CNG estate. In some situations, lack of data made the vehicles less comparable, but this is made clear in the model.

The comparisons are made through the lifetime of the vehicles, from the same start date. Vehicles are compared for identical types of usage, so the same assumptions of distance travelled are used for each comparison.

The model calculates, for each fuel and for each vehicle, the annual levels of emissions and the annual costs. This flow is totalled for the life of the vehicle, giving total lifetime emissions and costs. Within each vehicle type, comparisons are made with a baseline fuel (either conventional petrol or ULSD) to give the change in emissions or costs for replacing one baseline vehicle with an alternative fuelled vehicle.

By dividing the change in each emission by the change in costs, it is possible to determine the *cost-effectiveness* of each alternative fuel for each vehicle type. The results are expressed as the lifetime savings of pollutants per pound of additional cost incurred. It is important to bear in mind that some fuel may have good saving per pound spent, yet the absolute reduction possible from those fuels may be low.

Cost Effectiveness and Cost-Benefit Analysis

The comparison outlined above is a cost-effectiveness analysis approach. It expresses savings per unit spent. A full cost-benefit analysis would express both the costs and benefit (in emissions saved) in monetary terms, to give a single net benefit figure. This is only possible if there is a monetary value for emissions, which we do not have, meaning cost-effectiveness is a second-best approach. This approach does not limit the usefulness of the report, as other air quality and CO_2 reduction measures are also generally expressed in cost-effectiveness terms.

ASSUMPTIONS

For an analysis as potentially wide-ranging as this, and one containing so many data uncertainties, several assumption must be made. Modelling assumptions can be divided into defining assumptions, which narrow down the area of analysis, and simplifying assumptions, which can overcome data deficiencies or reduce complexity.

The main defining assumptions which are used in this model are:

- *Equal usage*. It is assumed that comparable vehicles face equal usage, so that the analysis can compare equivalent vehicles as necessary.
- *Equal survivability*. In order to assume equal usage without incurring extra replacement costs for some vehicles, it is necessary to assume that all vehicles have the same survivability.
- *Concurrent introduction*. It is assumed that compared vehicles are introduced in the same year, again to keep the comparisons similar and straightforward.
- *Equivalent location*. Connected with equal usage (in km) by assuming that vehicles are used in similar locations, we avoid the effects of varying.

The key simplifying assumptions are that:

- *Constant emissions factors*. Due to lack of information, it is not possible to decay the emissions factors with age of the vehicle. This assumption is relatively robust, since annual testing should catch vehicles whose emissions deteriorate significantly.

- *Range of data values*. In many cases, no data was available for minimum and maximum emissions factors, so a ±50% was used for regulated emission and ±20% for fuel economy and CO_2 emissions. It has been made clear where this assumption is utilised.

- *Equal discount rates*. There may be scope for assuming that users of alternative fuel vehicles will have a lower discount rate, as they are more interested in the environment. It is not feasible in the scope of this study to look at this, so discount rates are assumed equal.

- *No range limitations*. We have made the assumption, particularly relevant to battery electric vehicles, that there are no range limitations. In reality we would expect range limitations to arise due to both storage capacity and frequency of refuelling stations.

Broadly, the defining assumptions allow the model to meet its specifications, while the simplifying assumptions are forced due to data problems. Although the simplifying of assumptions, particularly taking account of range limitations, would be unlikely to change the fundamental results, they should be borne in mind when interpreting those results. For example, when comparing battery electric vehicles to other vehicles, the results will be more valid for urban use than company car use due to the range limitation.

PARAMETERS

The model has been made as variable as possible, in that as many of the main parameters as possible are changeable. The parameters are changed in the Assumptions sheet (A1), and automatically feed through into the rest of the model. These parameters can be used to examine different scenarios and test for sensitivities.

One key parameter alters the model so much as to be considered a scenario parameter, in that it fundamentally changes the results.

- *Comparator standard (A1.3.1)*. This parameter can be set between *base* and *future*. The base case uses emissions and costs data based upon current knowledge, whereas the future case uses an estimate of future emissions and costs for vehicles.

Most of the remaining parameters can be considered *sensitivity* parameters, because rather than changing the results specifically

- *Usage (A1.2)*. Vehicle usage rates change the type of comparison being made. For example, for cars the choices are *General, Company, Private* or *Second* car usage. These affect the pattern of vehicle utilisation (km) through its life.

- *Discount Rates (A1.4)*. The rate at which individuals, companies and society value current benefits over future benefits affect the relative benefits of different vehicles (see below). In general, a high discount rate favours vehicles whose costs occur in the future (high proportion of fuel costs over purchase costs).

- *Price fluctuation parameters (A1.5)*. The default forecasts of fuel prices come from DTI and HMCE. These can be changed automatically to reflect how important relative fuel price can be for relative cost-effectiveness.

Three sets of parameters are *policy* parameters, in that they measure the effect of things directly under control of the government.

- *Powershift rate (A1.3.2)*. The Powershift programme sets out to encourage switches to alternative fuels by compensating purchasers of alternative fuel vehicles by a percentage of the difference in price from a conventional fuel vehicle. This percentage can be changed.
- *Vehicle Excise Duty (A4)*. The rate of VED on different types of vehicles can be changed in the model. The rate can be changed for either vehicle types or give discounts for low-emission vehicles.
- *Fuel duty (A2, A3)*. Within the calculations for total fuel price are included the rate of fuel duty. By changing the relative rates, it is possible to model the effects of policy on private costs.

Finally two *time* parameters affect the time frame, but do not affect the relative results.

- *Base year for valuation (A1.2)*. Changes the year in which the costs are expressed for purposes of discounting (see below). The default is to express all costs in reference to the year 2000.
- *Year of vehicle introduction (A1.4)*. This is the year in which the vehicle is actually introduced. It will affect the absolute, but not relative, values of the cost-effectiveness. The default is 2000, and the year of introduction cannot be less than the base year for valuation (this produces an error).

Table C1: Range of vehicles and fuels used in present and future scenarios.

	Cars		LGVs		Buses		Rigids		Artics	
	Base	Future	Base	Future	Base	Future	Base	Future	Base	Future
Petrol	●		●							
Clean Petrol	●	●	●	●						
ULSD	●	●	●	●	●	●	●	●	●	●
NG		●		●	●	●	●	●	●	●
NG bi-fuel	●		●							
LPG		●		●	●	●	●	●		
LPG bi-fuel	●		●							
BEV	●	●		●	●					
P-HEV	●	●								
D-HEV					●	●				
H-FCV	●	●		●	●					

INPUT DATA

The most important input data are the emissions and costs data for each vehicle/fuel type/comparator standard. The discussion of the input data are dealt with elsewhere in this document. The combinations of vehicle types and fuel available in each scenario are shown in Table C1.

The input data is included in the spreadsheet as in Fig. 1. A minimum, median and maximum value are included for both the base and future scenarios. In the base scenario, the median is chosen as a specific vehicle. The minimum and maximum are based, where possible, on Powershift data. Where data is unavailable, a ±50% was used for regulated emission and ±20% for fuel economy and CO_2 emissions (see Tables E3 to E5 and Leaf Model Spreadsheets).

In the future scenario there is, of course, greater uncertainty. Therefore, the assumption has been made that future vehicles will beat future Euro Standards by the same margin as do Euro 2 vehicles. Therefore, future emissions are Euro 2 data multiplied by the ratio of Euro 4 to Euro 2 Standards. This follows the methodology adopted by previous DETR/NETCEN analyses. Attention needs to be given to cases where this method may prove problematic (e.g. future THC levels for NGVs or NO_x levels for ULSD).

In addition, parameters can be used to show improve emissions performance beyond the predicted level. These parameters control reductions against the predicted ('maximum') emission level and may be chosen for each fuel type separately for regulated pollutants (CO, NO_x, PM_{10}, THC) and global pollutants (GHG, CO_2, fuel efficiency). The median is then taken as being this reduction less than the maximum, and the minimum as twice the value below the maximum.

Figure C1: **Input data table for LPG car.**

CD4.2 **LPG Bi Fuel Car Emissions and Costs**

Year	Limits	CO g/km	PM g/km	NOx g/km	THC g/km	THC+NOx g/km	CO2 Tpipe	CO2 Prodn	CO2 Life	CH4 Tpipe	CH4 Prodn	CH4 Life	Fuel Con MJ/km	Price	Maint. £/km
Base	Max	1.40	-	0.17	0.11	0.29	204	22	226	-	0.05	0.05	2.96	11,500	0.025
	Median	0.36	-	0.13	0.08	0.21	153	18	171	-	0.04	0.04	2.37	11,500	0.025
	Min	0.04	-	0.02	0.02	0.04	136	15	151	-	0.03	0.03	1.97	11,500	0.025
Future	Max	0.16	-	0.05	0.03	0.08	173	19	192	-	0.04	0.04	2.51	11,300	0.015
	Median	0.13	-	0.04	0.02	0.06	130	15	146	-	0.03	0.03	2.01	11,300	0.015
	Min	0.10	-	0.03	0.02	0.05	116	13	128	-	0.03	0.03	1.68	11,300	0.015

Notes Med: Vauxhall Combo 1.4; Min, Max: Powershift Register

Costs for both present and future scenarios were determined as described elsewhere in the document. It was decided that price and maintenance costs should be held constant within vehicle fuel types, so that only one variable, the performance of the vehicle, is assumed to vary. If price was variable as well, it would be difficult to distinguish between cost effectiveness differences arising from variance in performance and variance in costs.

The base input data for fuel prices are taken from DTI and Customs & Excise forecasts. VED and fuel duty rates are based on current stated policy, or held constant. The kilometrage associated with each usage type comes from the Vehicle Market Model (DETR) or National Travel Survey (DETR).

STRUCTURE

Broadly, the model runs parallel calculations for each vehicle and each fuel type, and brings them together for comparisons in the Results file (RESULTS.XLS). The assumptions are defined in a single spreadsheet (ASSUMPTIONS.XLS) which links to each of the parallel calculations.

In general terms, the model consists of five stages for each parallel calculation.

1. *Define assumptions*. The assumptions to be used are defined at the outset. All the parameters defined above are selected at this stage.

2. *Define base data*. The base data for all the fuel types for a vehicle are included in a spreadsheet. This spreadsheet is used mainly for reference, as it is not expected that the base data will be changed regularly.

3. *Calculate costs and emissions per year*. For each year in the life of the vehicle, a kilometre age for each year is determined. Emissions and costs, expressed per km, are multiplied by this value and then discounted using the year and discount rate.

4. *Calculate lifetime costs and emissions*. The sum total of emissions and costs are calculated by summing up the discounted amounts in each year.

5. *Determine cost-effectiveness*. Cost effectiveness, in terms of emissions savings per pound spent, are calculated for each vehicle and fuel type. The results are expressed in absolute terms, and relative to the base case, which is assumed to be petrol for cars and diesel for all others.

6. *Output charts*. The cost effectiveness figures are linked to charts showing the minimum, median and maximum cost-effectiveness for each pollutant for each vehicle fuel type.

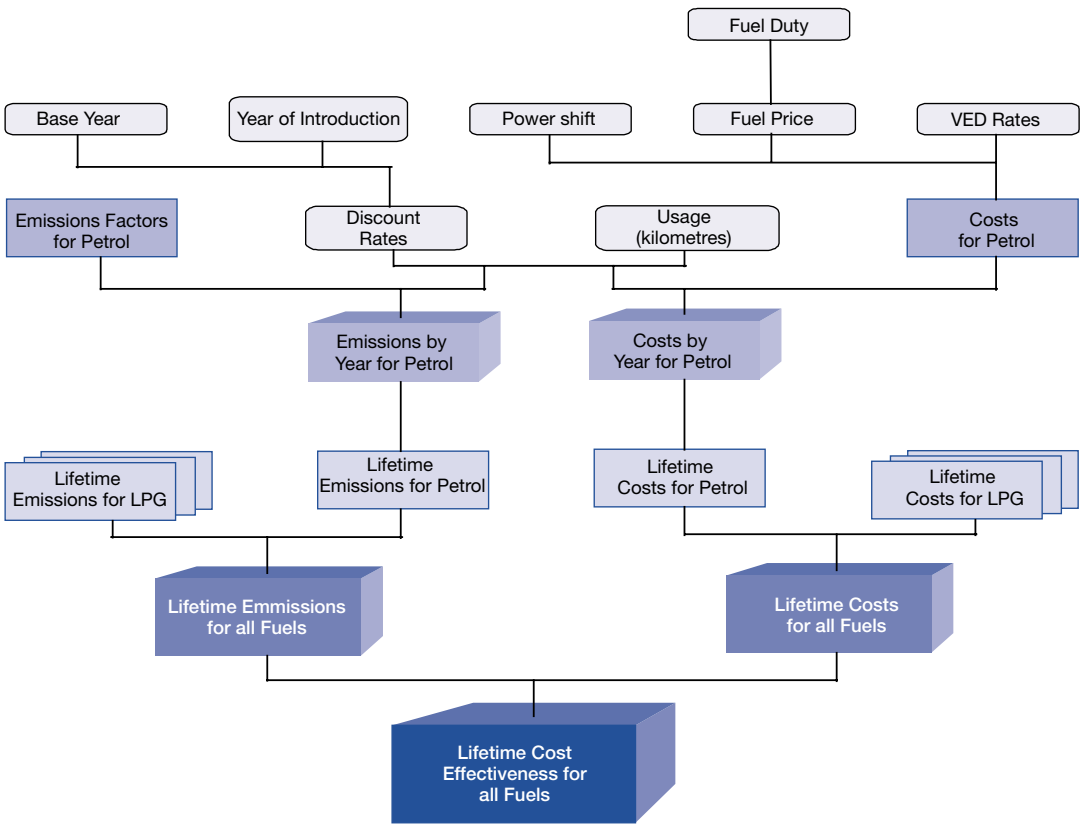
The structure of the model is shown in fig.2, with each of the parameters and sets of calculations set out. The flowchart has been simplified to show only one vehicle type, and to show only petrol. However, the structure for petrol is paralleled for all other fuels for that vehicle, and the whole spreadsheet is paralleled for the other vehicle types. Details of the calculations are in the following section.

CALCULATIONS

Although very broad in terms of coverage, it is not particularly complex in depth. The model is of a linear form which analyses only cost-effectiveness between single vehicles. It does not analyse the cost-effectiveness of a strategy to convert vehicles from one fuel type to another, as there is no behavioural element in the model. However, it is an important step towards such an analysis.

There are two main stages of calculation in the model: the calculation of costs and emissions by year, and the cost effectiveness calculations. Each of these is discussed in detail below. Other calculations are involved in the spreadsheet, but being minor they are better examined by looking at the model itself.

Figure C2: **Flowchart showing structure of the LEAF model for a specific scenario and vehicle type. This structure is repeated in parallel for the other vehicle types.**



Emissions Calculations

Lifetime emissions for each of the pollutants are on separate worksheets within each vehicle calculation spreadsheet (e.g., CARS.XLS). An example of the calculation tables are shown in fig. 3. The formula for calculating the lifetime emissions of a single pollutant is:

$$E_p = \sum_{t=b}^{n} \frac{e_p k_t}{(1+d^n)}$$

where

E_p is total lifetime emissions of the pollutant, p.

e_p is emissions of pollutant p per kilometre.

k_t is the number of kilometres travelled in that year.

d is the discount rate.

t is the year, where there are n years.

This procedure is repeated for each of the pollutants within each of the fuels. The entire process is then repeated for each of the vehicle types.

The inclusion of a discount factor is for completeness. Opinions vary on whether to discount emissions that occur in future years. Government practice is not to discount emissions, for example as in "An Economic Analysis of the National Air Quality Strategy Objectives" (1998). The argument is that the emissions are used to determine concentrations of pollutants, which then cause damage. If discounting occurs, it should be of the damage caused, not the emissions themselves. In any case, a very low discount factor would be argued for (see below). Nonetheless, a parameter has been included (A1.4.4) to choose whether to include a discount factor for emissions (A1.4.5) or not.

Types of Costs

The calculation of costs is more complex than for prices, in that there are several definitions of costs.

- *Private Costs*. Private costs are the costs faced by the individual, whatever their source. The individual pays the cost of the vehicle, the maintenance, and any taxes incurred. Private cost impacts on individual behaviour

- *Public Costs*. Public costs are the costs to society as a whole, whoever incurs them. Essentially, public costs are the resource costs because they reflect the land, labour and capital that could have been used for some other production. Taxes are *not* included, because tax paid by individuals is then used within the economy, so the two cancel each other out in the public view. Any welfare benefits or costs arising from the vehicle or from taxes would be included, but are beyond the scope of this model.

- *Exchequer Cost*. A switch between fuel types can cause a change in tax revenues over the life of a vehicle. This change in revenue will affect the exchequer, and as such should not be considered a true cost. The perspective of the Treasury is that of the public benefit, so exchequer costs are viewed as transfers within the economy.

Broadly speaking, the relationship between the types of costs is:

Public Cost = Private Cost – Exchequer cost

Although in practice this will vary, because the costs are discounted at different rates (see below). Prior to discounting, the above holds true.

Public cost is the recognised reference for cost-effectiveness analysis. The nature of pollution is that it is a cost incurred externally from the individual, and it would be inconsistent to express external benefits (pollution saved) in terms of internal costs. The convention is to express wider social benefits in terms of wider social costs, hence public cost.

Private cost is useful as an indicator of how attractive different fuels are to the individual. Combined with a behavioural model, the relative prices can be used to determine the shift between fuel types (not covered by this model). The Exchequer cost is of more use in terms of practicality and information. Since the purpose of the tax differentials is to encourage less polluting vehicles, the Treasury has already accepted the loss of revenue.

Discounting

In general, benefits or costs incurred immediately are of more importance to people than those incurred in the distant future. There are several reasons for this, including uncertainty about the future, and expectations about ability to deal with the benefits or costs in the

future. The discount rate is the method for taking this into account. For example, if you were to ask someone if they would prefer £101 now to £110 in a year's time, this implies their discount rate is at least 9%. If they were indifferent between £100 now and £110 in a year's time, then their discount rate is exactly 10%.

Discounting is a well-established principle in economics, and is always used to express a flow of costs as a single cost. By discounting costs in future years, all the costs can be added together because they are then expressed in terms of current value. Different individuals and groups will have different discount rates. However, there are conventions and estimates that can be used.

For private individuals, a very high discount rate is used. Empirically, we can see that people will often pay around 20% in annual interest on loans. This shows that they value current benefit much more than future benefit, as they trade off a larger repayment later for money in the present. The default for private individuals has been set at 20% in the model, but this can be changed (A1.4.2).

Companies tend to take a longer-term perspective on costs and benefits, and are more willing than private individuals to forego a current benefit for a larger benefit in the future. Again, based roughly on accepted interest rates and rates of return, we assume that the company discount rate (A1.4.1) is 9%.

Society as a whole takes the longest time perspective, and is most willing to forego current benefits for greater benefits in the future ('future generations'). The accepted figure used by the UK government for the public discount rate (A1.4.3) is 6%. Because it is the public discount rate, this is also the rate used by the Exchequer.

As mentioned above, it is sometimes considered that emissions should be discounted. The arguments against discounting still hold, and all outputs quoted in this document do not discount emissions. However, were the damage from emissions to be discounted, it would be at a rate of 3% or lower, since it relates to health (individuals value irreversible costs, e.g., death, more highly than reversible ones).

Costs Calculations

The costs incurred in ownership and operation of a vehicle can be broken down into several components.

- *Purchase price*. The price that must be paid for the vehicle at the place of purchase.
- *Powershift grant*. The Powershift programme reimburses a purchaser of a cleaner-fuel vehicle by a percentage of the difference between its purchase price and the price of the closest conventional substitute. This is paid for by the Exchequer.
- *Tax on purchase price*. The standard VAT rate of 17.5% is charged on car purchases. In the spreadsheets, this is included within the price.
- *Vehicle Excise Duty (VED)*. Vehicles must pay an annual tax in order to operate their vehicle. This is a tax on ownership and is independent of the age of the vehicle or its usage.

- *Fuel bill (underlying price)*. The underlying fuel price is the cost of fuel before any taxes are charged. This is multiplied by the fuel consumed that year. This represents the resource cost of providing the fuel.

- *Fuel bill (full price)*. Both VAT and excise duties are paid on fuel, so the full price will include the underlying price plus taxes. This increases the fuel bill faced.

- *Maintenance costs*. Vehicles suffer wear and tear, so a simplified maintenance cost in pence per km is assumed.

In order to express these costs in terms of public, private and exchequer costs, these costs are grouped into eight categories. The most important difference between each public and private element is the rate at which it is discounted. The private categories use either the private or company discount factor (depending on vehicle type), while public uses the public discount factor (which is the same for the Exchequer).

- *Private Capital Cost*. This is the cost an individual faces for ownership of a vehicle, and includes only the purchase price excluding VAT.

- *Private Capital Tax*. Taxes an individual faces for vehicle ownership: VAT on purchase price; the Powershift grant; and VED through the vehicle's life.

- *Public Capital Cost*. The public capital cost is the resource cost involved in ownership of a vehicle, so is only the purchase price excluding VAT.

- *Private Capital Tax*. The taxes paid to the Exchequer: VAT on purchase price; the Powershift grant; and VED through the vehicle's life.

- *Private Operating Cost*. The non-tax cost of operating a vehicle is the fuel bill (underlying price) and the maintenance (excluding VAT).

- *Private Operating Tax*. The taxes paid on fuel and the VAT paid on maintenance.

- *Public Operating Cost*. Taxes on fuel are transfers, so in the public view only the fuel bill (underlying price) and maintenance costs (excluding VAT) are considered.

- *Public Operating Tax*. Fuel taxes and VAT on maintenance paid to the Exchequer.

The part of the spreadsheet which calculates these costs is shown in fig. 4. The formula for the calculation of each element are given below in fig. 5. The distinction in each case between private and public costs or tax is the discount factor which is used.

Figure C3: Calculation of emissions per year and lifetime emissions for LPG cars (table abbreviated, years 2009 to 2034 hidden).

C8.1

Year			2000	2001	2002	2003	2004	2005	2006	2007	2008	Cumulative
Age of Vehicle			1	2	3	4	5	6	7	8	9	Sum
Weighted km (000)			25.5	21.7	20.3	17.9	16.5	15.4	14.5	13.6	12.6	203.5
Emissions Discount Rate			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
CO	Max	1.400	36	30	28	25	23	22	20	19	18	285
CO	Median	0.356	9	8	7	6	6	5	5	5	4	72
CO	Min	0.040	1	1	1	1	1	1	1	1	1	8
PM	Max	0.000	0	0	0	0	0	0	0	0	0	0.0
PM	Median	0.000	0	0	0	0	0	0	0	0	0	0.0
PM	Min	0.000	0	0	0	0	0	0	0	0	0	0.0
NOx	Max	0.173	4	4	4	3	3	3	3	2	2	35.2
NOx	Median	0.127	3	3	3	2	2	2	2	2	2	25.9
NOx	Min	0.024	1	1	0	0	0	0	0	0	0	4.9

These elements are used to construct the three types of lifetime costs for each vehicle fuel type, as defined above:

Private Cost = PvtCapCost + PvtCapTax + PvtOpCost + PvtOpTax

Public Cost = PblCapCost + PblOpCost

Exchequer Cost = –(PblCapTax + PblOpTax)

Figure C4: Calculation of costs per year and lifetime costs for LPG cars (table abbreviated, years 2009 to 2034 hidden, min and max hidden).

F Con	Max	0.13	3203	2728	2545	2244	2074	1936	1817	1702	1579	25530
F Con	Median	0.10	2566	2185	2039	1798	1662	1552	1456	1363	1265	20456
F Con	Min	0.08	2135	1818	1697	1496	1383	1291	1211	1134	1053	17020

C8.2

Year			2000	2001	2002	2003	2004	2005	2006	2007	2008	Cumulative
Age of Vehicle			1	2	3	4	5	6	7	8	9	Sum
Private Discount Factor			1.00	0.80	0.64	0.51	0.41	0.33	0.26	0.21	0.17	
Public Discount Factor			1.00	0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61	
Pvt Capital Cost		11500	11500	0	0	0	0	0	0	0	0	11500
Publ Capital Cost		11500	11500	0	0	0	0	0	0	0	0	11500
VED			125	125	125	125	125	125	125	125	125	2900
Pvt Capital Tax		750	-625	100	80	64	51	41	33	26	21	-127
Publ Capital Tax		750	-625	118	110	104	98	92	86	81	76	846
F Bill (fp)	Median		924	787		647	598	559	524	491	456	7367
F Bill (up)	Median		594	506	472	416	385	359	337	316	293	4736
Pvt Op Cost	Median	0.03	1232	840	627	442	327	244	183	137	102	4335
Publ Op Cost	Median	0.03	1232	987	865	717	623	547	482	425	370	7359
Pvt Op Tax	Median		330	225	168	118	88	65	49	37	27	1161
Publ Op Tax	Median		330	264	232	192	167	146	129	114	99	1971

Costs Effectiveness Calculations

As stated in the Overview, the end output of the LEAF model is cost-effectiveness. The cost-effectiveness is expressed as a single figure for each pollutant over the lifetime of the vehicles. When preparing cost-effectiveness, it is important to explicitly define the base case, since this will determine the degree of benefit change or cost change.

In this model, the default is to use regular petrol for cars, and ULSD for LGVs, buses and HGVs.

Cost-effectiveness can be expressed as *average* or *marginal* cost-effectiveness. The average would be the total emissions divided by the total cost. This measurement is not intuitive because it looks at how cost-effective a vehicle is at producing pollution. Cost effectiveness is normally expressed in terms of benefit, not cost (pollution). Instead, marginal cost effectiveness is used. This expresses the change in pollutants over the change in costs.

Marginal cost-effectiveness must be expressed in terms of a base case. For example, comparing LPG to Petrol:

$$CE_{LPG} = \frac{P_{Petrol} - P_{LPG}}{C_{LPG} - C_{Petrol}}$$

Figure C5: Formulae for calculating the elements of cost in the model.

$$PvtCapCost = \frac{PP_{excl}}{\left(1 + d_i^b\right)}$$

$$PvtCapTax = \frac{\left(PP_{incl} - PP_{excl}\right) - PSG}{\left(1 + d_i^b\right)} + \sum_{t=b}^{n} \frac{VED_t}{\left(1 + d_i^t\right)}$$

$$PblCapCost = \frac{PP_{excl}}{\left(1 + d_s^b\right)}$$

$$PblCapTax = \frac{\left(PP_{incl} - PP_{excl}\right) - PSG}{\left(1 + d_s^b\right)} + \sum_{t=b}^{n} \frac{VED_t}{\left(1 + d_s^t\right)}$$

$$PvtOpCost = \sum_{t=b}^{n} \frac{FB_{up} + M_{excl}}{\left(1 + d_i^t\right)} \qquad PvtOpTax = \sum_{t=b}^{n} \frac{\left(FB_{fp} - FB_{up}\right) + \left(M_{incl} - M_{incl}\right)}{\left(1 + d_i^t\right)}$$

$$PblOpCost = \sum_{t=b}^{n} \frac{FB_{up} + M_{excl}}{\left(1 + d_i^t\right)} \qquad PblOpTax = \sum_{t=b}^{n} \frac{\left(FB_{fp} - FB_{up}\right) + \left(M_{incl} - M_{incl}\right)}{\left(1 + d_i^t\right)}$$

where PP_{excl} is purchase price excluding VAT.

PP_{incl} is purchase price including VAT.

d_u is the private (or individual) discount rate.

d_s is the public (or social) discount rate.

PSG is the Powershift grant.

VED is Vehicle Excise Duty per year.

FB_{up} is the fuel bill at underlying price of fuel.

FB_{fp} is the fuel bill at the full price of fuel.

M_{excl} is the maintenance cost excluding VAT.

M_{incl} is the maintenance cost including VAT.

b is the year of vehicle introduction relative to the base year.

n is the final year of vehicle life relative to the base year.

t is the current year of the iteration relative to the base year.

This approach is consistent with how cost comparisons are made for other environmental cost-effectiveness comparisons in government policy. However, in this case there are some complications. It is possible that in a comparison costs are either higher or lower, and emissions of different pollutants can also be higher or lower. Considering this in the context of the above equation, we can see in table below that, mathematically, (More Pollution, More Cost) will have the same sign as (Less Pollution, Less Cost). Thus, it is not possible to tell the difference between an all round worsening and an all-round improvement. Similarly, (Less Pollution, More Cost) will have the same sign as (More Pollution, Less Cost).

	Relative Pollution	
Relative Costs	**More (–)**	**Less (+)**
More (+)	–	+
Less (–)	+	–

Cost-Effectiveness analysis of Cleaner Fuels and Vehicles – Results

SCENARIOS

Given the large number of parameters of the model, for the purposes of comparing the fuel-technology options it is necessary to limit the number of cases considered. To do this a number of ***'base' and 'future' scenarios*** are constructed which reduce the amount of output data. With careful choice of scenarios, the essential outputs/comparisons of the fuel-technology options is more easily achieved.

Base scenarios use the emission and cost data collected on behalf of the Alternative Fuels Group, the 'median' values of which is shown in the Tables in Section E. The assumptions for this data are discussed in Section C.1. The **future scenarios** use the year 2005 predictions were discussed in Section C. These predictions predict percentage changes from current emission and cost data. These percentage predictions form part of the definition of the future scenarios and is summarised in the following tables.

An exhaustive combination of scenarios was conducted utilising the cost effectiveness model, the results of which were compared to assess whether the results for each fuel were dependent upon specific assumptions. The results were not significantly affected by the different scenarios and therefore only key scenarios are summarised below, these being general usage with two alternate time settings, the year 2000 and the future. The discussion of cost effectiveness is framed in terms of public expenditure.

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S1.0	Car	Base	General	0%	Petrol

Cleaner Petrol – the limits on the error bars (see Charts B2–B9) indicate no significant changes in PM_{10}, NO_x or CO_2. Therefore an analysis for cleaner petrol cars is not possible.

CNG – Low to moderate reductions and moderate to high cost-effectiveness for NO_x (1.7–6.2 g/£).
Low to moderate reductions and high cost-effectiveness for CO_2 (2.0–2.4kg/£).

LPG – Low to moderate reductions and moderate cost-effectiveness for NO_x (1.7–4.8 g/£).
Low to moderate reductions and high to highest cost-effectiveness for CO_2 (2.0–2.8kg/£).

BEV – Equal largest reduction with a moderate cost-effectiveness for NO_x (0.9–4.9 g/£).
Moderate to high reduction and moderate cost-effectiveness for CO_2 (1.4–2.3kg/£).

P-HEV – Moderate reduction with a moderate cost-effectiveness for NO_x (0.4–5.4 g/£).
Moderate reduction and a moderate to high cost-effectiveness for CO_2 (about 2.6kg/£).

H-FCV – Equal largest reduction with a very low cost-effectiveness for NO_x (0.1–0.4 g/£).
Largest reduction and very low cost-effectiveness for CO_2 (0.2–0.3kg/£).

Scenario	**Vehicle Type**		**Comparative Standard**		**Usage**		**Powershift**		**Base Vehicle**
S1.1	Car		Future		General		0%		Petrol
Parameters	Petrol	ULSD	CNG	LPG	P-HEV	D-HEV	BEV	H-FCV	M-FCV
Reg. range	20%	20%	20%	20%	20%	20%	N/a	N/a	–
CO2/Fuel Con	85%	85%	80%	85%	70%	70%	90%	75%	–

Cleaner Petrol – by year 2005, all petrol conforms to low benzene and low sulphur standards associated with what is currently known as 'cleaner petrol'.

CNG – Relatively low reductions and moderate cost-effectiveness for NO_x (1.0–1.3 g/£).
Relatively low reductions and moderate to high cost-effectiveness for CO_2 (2.9–3.4kg/£).

LPG – Relatively low reductions and moderate cost-effectiveness for NO_x (0.8–1.2 g/£).
Relatively low reductions and moderate cost-effectiveness for CO_2 (2.2–3.1kg/£).

BEV – Equal largest reduction with a moderate cost-effectiveness for NO_x (0.6–1.0 g/£).
Moderate reduction and a low to moderate cost-effectiveness for CO_2 (1.2–1.9kg/£).

P-HEV – Moderate reduction with a moderate to highest cost-effectiveness for NO_x (1.0–1.8 g/£).
Moderate reduction and highest cost-effectiveness for CO_2 (3.5–4.3kg/£).

H-FCV – Equal largest reduction with a very low cost-effectiveness for NO_x (0.1–0.2 g/£).
Largest reduction and very low cost-effectiveness for CO_2 (0.3–0.4kg/£).

Scenario	**Vehicle Type**	**Comparative Standard**	**Usage**	**Powershift**	**Base Vehicle**
S1.2	Car	Base	General	0%	ULSD

CNG – Moderate reductions and moderate to high cost-effectiveness for NO_x (15.8–19.3 g/£).
Moderate to high reductions and moderate cost-effectiveness for PM_{10} (1.3–2.6 g/£).
Possible increase in CO_2.

LPG – Moderate reductions and moderate to highest cost-effectiveness for NO_x (17.2–22.3 g/£).
Moderate to high reductions and moderate to highest cost-effectiveness for PM_{10} (1.5–3.4 g/£).
Possible increase in CO_2.

BEV – Moderate to equal highest reduction and low to moderate cost-effectiveness for NO_x (6.4–9.4 g/£).
Equal highest reductions and low to moderate cost-effectiveness for PM_{10} (0.4–1.2 g/£).
Moderate reduction and a moderate cost-effectiveness for CO_2 (0.6–0.8kg/£).

P-HEV – Moderate to high reduction with a moderate cost-effectiveness for NO_x (9.0–12.3 g/£).
Moderate to high reductions and moderate cost-effectiveness for PM_{10} (0.6–1.9 g/£).
Moderate reduction and a moderate to highest cost-effectiveness for CO_2 (0.4–1.4kg/£).

H-FCV – Moderate to equal highest reduction with a very low cost-effectiveness for NO_x (0.7–0.9 g/£).
Equal highest reductions and very low cost-effectiveness for PM_{10} (<0.1 g/£).
Largest reduction and very low cost-effectiveness for CO_2 (~0.1kg/£).

Scenario	**Vehicle Type**		**Comparative Standard**		**Usage**		**Powershift**	**Base Vehicle**	
S1.3	Car		Future		General		0%	ULSD	
Parameters	Petrol	ULSD	CNG	LPG	P-HEV	D-HEV	BEV	H-FCV	M-FCV
Reg. Range	20%	20%	20%	20%	20%	20%	N/a	N/a	–
CO2/Fuel Con	85%	85%	80%	85%	70%	70%	90%	75%	–

CNG – Moderate reductions and moderate to high cost-effectiveness for NO_x (7.0–7.6 g/£).
Moderate to high reductions and moderate cost-effectiveness for PM_{10} (0.7–0.8 g/£).
Possible slight increase in CO_2.

LPG – Moderate reductions and highest cost-effectiveness for NO_x (7.9–9.3 g/£).
Moderate to high reductions and highest cost-effectiveness for PM_{10} (0.9–1.0 g/£).
Possible increase in CO2.

BEV – Moderate to equal highest reduction and low cost-effectiveness for NO_x (1.7–2.9 g/£).
Equal highest reductions and low cost-effectiveness for PM_{10} (0.1–0.2 g/£).
Moderate reduction and a low to moderate cost-effectiveness for CO_2 (0.6–0.9kg/£).

P-HEV – Moderate reduction with a moderate cost-effectiveness for NO_x (3.8–6.5 g/£).
Moderate to high reductions and moderate cost-effectiveness for PM_{10} (0.3–0.6 g/£).
Moderate reduction and the highest cost-effectiveness for CO_2 (1.7–2.2kg/£).

H-FCV – Moderate to equal highest reduction with a very low cost-effectiveness for NO_x (0.4–0.5 g/£).
Equal highest reductions and very low cost-effectiveness for PM_{10} (<0.04 g/£).
Largest reduction and very low cost-effectiveness for CO_2 (~0.2kg/£).

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S2.0	LGV	Base	General	0%	Petrol

Cleaner Petrol – the only cost-effectiveness analysis which has been conducted for this report indicates, that for LGVs, cleaner petrol is highly cost-effective in reducing NO_x (79–158 g/£). Moreover, its cost-effectiveness is over 7 times the cost-effectiveness of gaseous fuels for NO_x reduction. However, it should be noted that the absolute reduction in NO_x is less than for the gaseous fuels considered. CO_2 emissions are not significantly changed.

Scenario	Vehicle Type		Comparative Standard		Usage		Powershift		Base Vehicle
S2.1	LGV		Future		General		0%		Petrol
Parameters	Petrol	ULSD	CNG	LPG	P-HEV	D-HEV	BEV	H-FCV	M-FCV
Reg. Range	20%	20%	20%	20%	20%	20%	–	–	–
CO2/Fuel Con	85%	85%	80%	85%	–	–	–	–	–

Cleaner Petrol – by year 2005, all petrol conforms to low benzene/low sulphur standards associated with what is currently known as 'cleaner petrol'.

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S2.2	LGV	Base	General	0%	ULSD

CNG – Equal highest reductions and equal highest cost-effectiveness for NO_x (18.4–41.4 g/£).
Equal highest reductions and equal highest cost-effectiveness for PM_{10} (3.5.3–7.9 g/£).
No significant change in CO_2.

LPG – Equal highest reductions and equal highest cost-effectiveness for NO_x (19.1–42.2 g/£).
Equal highest reductions and equal highest cost-effectiveness for PM_{10} (3.6–8.0 g/£).
Increase in CO_2.

Scenario	Vehicle Type		Comparative Standard		Usage		Powershift	Base Vehicle	
S2.3	JGV		Future		General		0%	ULSD	
Parameters	Petrol	ULSD	CNG	LPG	P-HEV	D-HEV	BEV	H-FCV	M-FCV
Reg. Range	20%	20%	20%	20%	–	–	–	–	–
CO2/Fuel Con	85%	85%	80%	85%	–	–	–	–	–

CNG – Equal highest reductions and equal highest cost-effectiveness for NO_x (21.6–22.6 g/£).
Equal highest reductions and moderate (similar to LPG) cost-effectiveness for PM_{10} (4.1–4.3 g/£).
Small reduction of CO_2 with an associated cost-effectiveness of 1.0–1.2kg/£.

LPG – Equal highest reductions and equal highest cost-effectiveness for NO_x (20.1–22.0 g/£).
Equal highest reductions and moderate (similar to CNG) cost-effectiveness for PM_{10} (3.9–4.1 g/£).
Increase in CO_2.

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S3.0	Bus	Base	General	0%	ULSD

ULSD+CRT – Lowest reduction and highest cost-effectiveness for NO_x (36–107 g/£).
Moderate to high reductions and highest cost-effectiveness for PM_{10} (2.8–8.3 g/£).
No significant change in CO_2.

CNG – Low reduction and moderate cost-effectiveness for NO_x (9.8–25.7 g/£).
Moderate to high reductions and relatively low cost-effectiveness for PM_{10} (0.3–0.6 g/£).
No significant change in CO_2.

LPG – Moderate reductions and moderate cost-effectiveness for NO_x (22–57 g/£).
Moderate to high reductions and relatively low cost-effectiveness for PM_{10} (0.4–0.9 g/£).
No significant change in CO_2.

BEV – Largest reduction and moderate cost-effectiveness for NO_x (20–59 g/£).
Largest reduction and relatively low cost-effectiveness for PM_{10} (0.2–0.7 g/£).
Largest reduction and highest cost-effectiveness for CO_2 (1.1–1.6kg/£).

D-HEV – Moderate to high reduction with a moderate cost-effectiveness for NO_x (11–34 g/£).
Moderate to high reductions and relatively low cost-effectiveness for PM_{10} (0.1–0.4 g/£).
Large reduction and a high cost-effectiveness for CO_2 (0.6–1.0kg/£).

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S3.1	Bus	Future	General	0%	ULSD

Parameters	Petrol	ULSD	CNG	LPG	P-HEV	D-HEV	BEV	H-FCV	M-FCV
Reg. Range	–	20%	30%	30%	–	20%	N/a	N/a	–
CO2/Fuel Con	–	102%	95%	95%	–	70%	90%	–	–

ULSD+CRT – Lowest reduction and moderate cost-effectiveness for NO_x (43–71 g/£).
Moderate to high reductions and highest cost-effectiveness for PM_{10} (0.9–1.5 g/£).
No significant change in CO_2.

CNG – Low to moderate reduction and lowest cost-effectiveness for NO_x (13–17g/£).
Moderate to high reductions and relatively low cost-effectiveness for PM_{10} (0.07–0.09 g/£).
Small reduction and very low cost-effectiveness for CO_2 (0.6–0.7kg/£).

LPG – Moderate reductions and low cost-effectiveness for NO_x (27–29 g/£).
Moderate to high reductions and relatively low cost-effectiveness for PM_{10} (0.10–0.12 g/£).
Small reduction and very low cost-effectiveness for CO_2 (0.9–1.0kg/£).

BEV – Largest reduction and moderate cost-effectiveness for NO_x (40–66 g/£).
Largest reduction and relatively low cost-effectiveness for PM_{10} (0.12–0.19 g/£).
Equal largest reduction and moderate cost-effectiveness for CO_2 (5.6–8.3kg/£).

D-HEV – Moderate to high reduction with highest cost-effectiveness for NO_x (63–134 g/£).
Moderate to high reductions and low to moderate (second highest) cost-effectiveness for PM_{10} (0.20–0.42 g/£).
Equal largest reduction and highest cost-effectiveness for CO_2 (11–22kg/£).

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S4.0	Rigid	Base	General	0%	ULSD

ULSD+CRT – Moderate to large reductions and highest cost-effectiveness for NO_x (57–144 g/£).
Moderate to large reductions and highest cost-effectiveness for PM_{10} (7.4–18.8 g/£).
No significant change is predicted for CO_2 or GHGs.

CNG – Moderate to large reductions and relatively low cost-effectiveness for NO_x (4–27 g/£).
Moderate to large reductions and relatively low cost-effectiveness for PM_{10} (0.9–2.4 g/£).
Reduction and low cost-effectiveness for CO_2 (0.22–0.25kg/£) (GHGs are increased).

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S4.1	Rigid	Future	General	0%	ULSD

Parameters	Petrol	ULSD	CNG	LPG	P-HEV	D-HEV	BEV	H-FCV	M-FCV
Reg. Range	–	20%	30%	–	–	–	–	–	–
CO2/Fuel Con	–	102%	95%	–	–	–	–	–	–

ULSD+CRT – Moderate to largest reductions and highest cost-effectiveness for NO_x (141–185 g/£).
Moderate to large reductions and highest cost-effectiveness for PM_{10} (2.6–3.4 g/£).
No significant change is predicted for CO_2 or GHGs.

CNG – Moderate to large reductions and relatively low cost-effectiveness for NO_x (2–25 g/£).
Moderate to large reductions and relatively low cost-effectiveness for PM_{10} (0.35–0.40 g/£).
Reduction and low cost-effectiveness for CO_2 (1.6–1.7kg/£) (No increase in GHGs).

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S5.0	Artic	Base	General	0%	ULSD

CNG – Significant reductions and cost-effectiveness for NO_x of 51–108 g/£.
Significant reductions and cost-effectiveness for PM_{10} of 2.8–5.8 g/£.
Slight increase in CO_2 and GHGs.

Scenario	Vehicle Type	Comparative Standard	Usage	Powershift	Base Vehicle
S5.1	Artic	Future	General	0%	ULSD

Parameters	Petrol	ULSD	CNG	LPG	P-HEV	D-HEV	BEV	H-FCV	M-FCV
Reg. Range	–	20%	30%	–	–	–	–		–
CO2/Fuel Con	–	102%	95%	–	–	–	–	–	–

CNG – Significant reductions and cost-effectiveness for NO_x of 35–39 g/£.
Significant reductions and cost-effectiveness for PM_{10} of 0.49–0.56 g/£.
Slight increase in CO_2 and GHGs.

Summary of the Cost-Effectiveness Analysis

From the results of the cost-effectiveness analysis, the following conclusions can be drawn regarding the most cost-effective fuel-technology options (as compared to the baseline used). The following section highlights and summarises the moderate to highest cost-effective options which also provide at a significant reduction in the emission in question.

Note that for many comparisons, there may be a significant reduction in emissions even if the cost-effectiveness is very low in comparison with other fuels considered. Alternatively, there may appear to be a high cost-effectiveness, even though the reduction achieved in not significant. Therefore, the following cost-effectiveness summary needs to be considered together with the significance of the reduction achieved. These are discussed in the previous section.

CAR – YEAR 2000 – PETROL BASELINE

- CNG, LPG, BEV and P-HEV all show at least a moderate cost-effectiveness for NO_x. The level of reduction of NO_x is larger for electric drive-trains.
- CNG, LPG, BEV and P-HEV all show at least a moderate cost-effectiveness for CO_2 with BEVs being slightly lower than the other options. The level of reduction of CO_2 is larger for electric drive-trains.
- CNG, LPG, BEV and P-HEV are all low in particulates.

CAR – FUTURE – PETROL BASELINE

The picture is broadly similar for gaseous fuels and the electric options in this vehicle category. The main change is:

- an improvement in the cost-effectiveness of P-HEV for reducing NO_x and CO_2 (highest cost-effectiveness for both).

CAR – YEAR 2000 – ULSD BASELINE

- CNG, LPG both show a moderate to high cost-effectiveness for NO_x (LPG is highest) and at least a moderate cost-effectiveness for PM_{10} (LPG is highest).
- BEV and P-HEV both show a low to moderate cost-effectiveness for NO_x (BEV is highest) and a low to moderate cost-effectiveness for PM_{10} (P-HEV is higher).
- BEV and P-HEV both show at least a moderate cost-effectiveness for CO_2 (P-HEV is the highest)

CAR – FUTURE – ULSD BASELINE

- The picture is broadly similar for gaseous fuels and the electric options to the Year 2000 comparison. However, it can be seen that:
- The gaseous fuels continue to be more cost-effective for reducing NO_x and PM_{10}.
- The electric drive train options continue to be cost-effective for reducing CO_2.

LGV – YEAR 2000 – PETROL BASELINE

- Cleaner petrol shows the highest cost-effectiveness in reducing NO_x.

LGV – YEAR 2000 – ULSD BASELINE

- Gaseous fuels are both moderately to highly cost-effective in reducing both PM_{10} and NO_x.

LGV – FUTURE – ULSD BASELINE

The picture is broadly similar for gaseous fuels to the Year 2000 comparison.

BUS – YEAR 2000 – ULSD BASELINE

- ULSD+CRT shows the highest cost-effectiveness values for NO_x and PM_{10}. However, for NO_x emissions, the reduction is relatively small (smallest).
- CNG and LPG both have a moderate cost-effectiveness in reducing NO_x.
- BEV and D-HEV both show moderate cost-effectiveness values for reduction in NO_x and a high cost-effectiveness for CO_2 (BEV highest).

BUS – FUTURE – ULSD BASELINE

The relative merits in the future case change somewhat from the Year 2000 scenario:

- ULSD+CRT shows the highest cost-effectiveness values for PM_{10} and a moderate cost-effectiveness in reducing NO_x. However, for NO_x emissions, the reduction is relatively small (smallest).
- BEV shows moderate cost-effectiveness values for reduction in both NO_x and CO_2.
- D-HEV shows the highest cost-effectiveness values for reduction in both NO_x and CO_2 and a moderate (second highest) cost-effectiveness for PM_{10}.

RIGID – YEAR 2000 – ULSD BASELINE

- ULSD+CRT has the highest cost-effectiveness for both NO_x and PM_{10}.

RIGID – FUTURE – ULSD BASELINE

The future scenario is largely unchanged from the base case.

ARTIC – YEAR 2000 – ULSD BASELINE

As only one alternative to ULSD is considered, it is not possible to draw any conclusions about the relative cost-effectiveness of CNG in reducing emissions. However, there are:

- significant reductions for both PM_{10} and NO_x as compared to ULSD.

ARTIC – FUTURE – ULSD BASELINE

Significant reductions in NO_x and PM_{10} are still achieved, but there is:

- a reduction in the absolute cost-effectiveness vales as compared to Year 2000 scenarios.

Conclusions from the Cost-Effectiveness Analysis

From the findings of the cost-effectiveness analysis, in broad terms and focusing on the most significant potential benefits associated with each fuel-technology option, we can conclude that:

FOR LIGHT-DUTY VEHICLES (PETROL BASELINE)

- Cleaner petrol is highly cost-effective in reducing NO_x (shown for LGVs only).
- CNG, LPG, BEV and P-HEV all show at least a moderate cost-effectiveness for NO_x. The level of reduction of NO_x is larger for electric drive-trains.
- CNG, LPG, BEV and P-HEV all show at least a moderate cost-effectiveness for CO_2 with BEVs being slightly lower than the other options. The level of reduction of CO_2 is larger for electric drive-trains.
- CNG, LPG, BEV and P-HEV are all low in particulates.
- Future trend is an improvement in the cost-effectiveness of P-HEV for reducing NO_x and CO_2 (highest cost-effectiveness for both).

FOR LIGHT-DUTY VEHICLES (ULSD BASELINE)

- CNG, LPG both show a moderate to high cost-effectiveness for NO_x (LPG is highest) and at least a moderate cost-effectiveness for PM_{10} (LPG is highest).
- BEV and P-HEV both show a low to moderate cost-effectiveness for NO_x (BEV is highest) and a low to moderate cost-effectiveness for PM_{10} (P-HEV is higher).
- BEV and P-HEV both show at least a moderate cost-effectiveness for CO_2 (P-HEV is the highest).
- Future trends suggest that the gaseous fuels continue to be more cost-effective for reducing NO_x and PM_{10} and the electric drive train options continue to be cost-effective for reducing CO_2.

FOR HEAVY-DUTY VEHICLES (ULSD BASELINE)

- ULSD+CRT shows at least a moderate cost-effectiveness in reducing NO_x and the highest cost-effectiveness values for PM_{10}. However, in some cases for NO_x emissions, the reduction is relatively small.
- CNG and LPG both have a moderate cost-effectiveness in reducing NO_x.
- BEV shows a moderate cost-effectiveness value for reduction in NO_x and the highest cost-effectiveness for CO_2.
- D-HEV shows a moderate cost-effectiveness values for reduction in NO_x and a high cost-effectiveness for CO_2.
- Future trend for D-HEV is a significant improvement in cost-effectiveness for reducing NO_x, PM_{10} and CO_2. In the future, for buses, D-HEV is predicted to be the most cost-effective option for reducing NO_x and CO_2.
- Future trend is for a reduction in the relative cost-effectiveness of gaseous fuels in the reduction of NO_x. Also trends suggests for BEVs a reduction in the cost-effectiveness for reducing CO_2.

USE OF COST-EFFECTIVENESS RESULTS IN FORMATION OF RECOMMENDATIONS

- The conclusions from the cost-effectiveness analysis can be used in conjunction with other data discussed in Section B to guide the building of recommendations for the use of alternative fuels and vehicle technologies. In particular, the findings of the cost-effectiveness analysis strongly indicate and support the following recommendations:
- For light-duty vehicles, gaseous fuels (NG and LPG) should continue to be encouraged on the basis of their moderate cost-effectiveness in reducing NO_x, PM_{10} (compared to diesel) and CO_2 (compared to petrol). For heavy-duty vehicles, gaseous fuels should continue to be encouraged on the basis of their moderate cost-effectiveness in reducing NO_x.

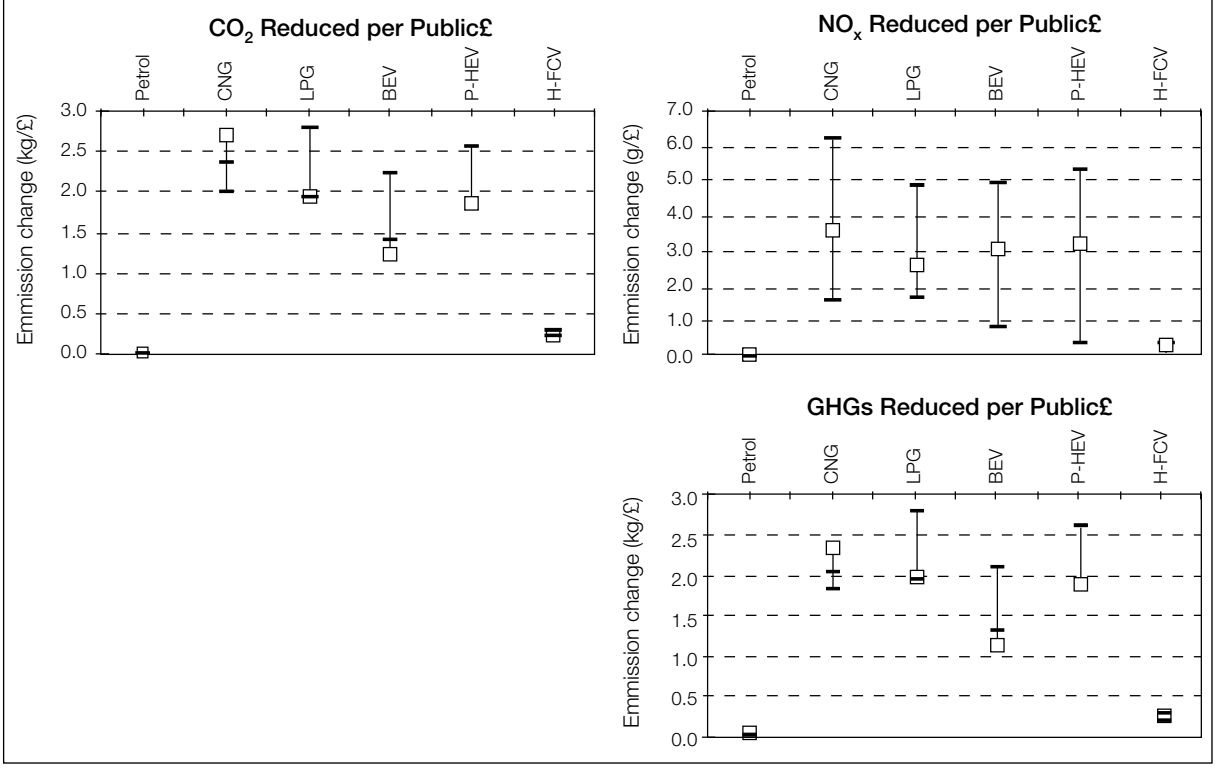
- For heavy duty diesel vehicles, the introduction of after-treatment systems (such as CRT) should be encouraged on the basis of the high cost-effectiveness of this option in reducing PM_{10} and NO_x. This implies the use of ultra low sulphur diesel (<50 ppm) which will be mandatory in Europe from 2005 and is already used in the UK.

- For light duty vehicles, battery electric vehicles (BEVs) should be supported on the basis of their moderate cost-effectiveness in reducing urban NO_x and lifecycle CO_2 and a low to moderate cost-effectiveness in reducing urban PM_{10} (compared to diesel baseline). Battery electric buses should be supported on the basis of their at least moderate cost-effectiveness in reducing urban NO_x and lifecycle CO_2.

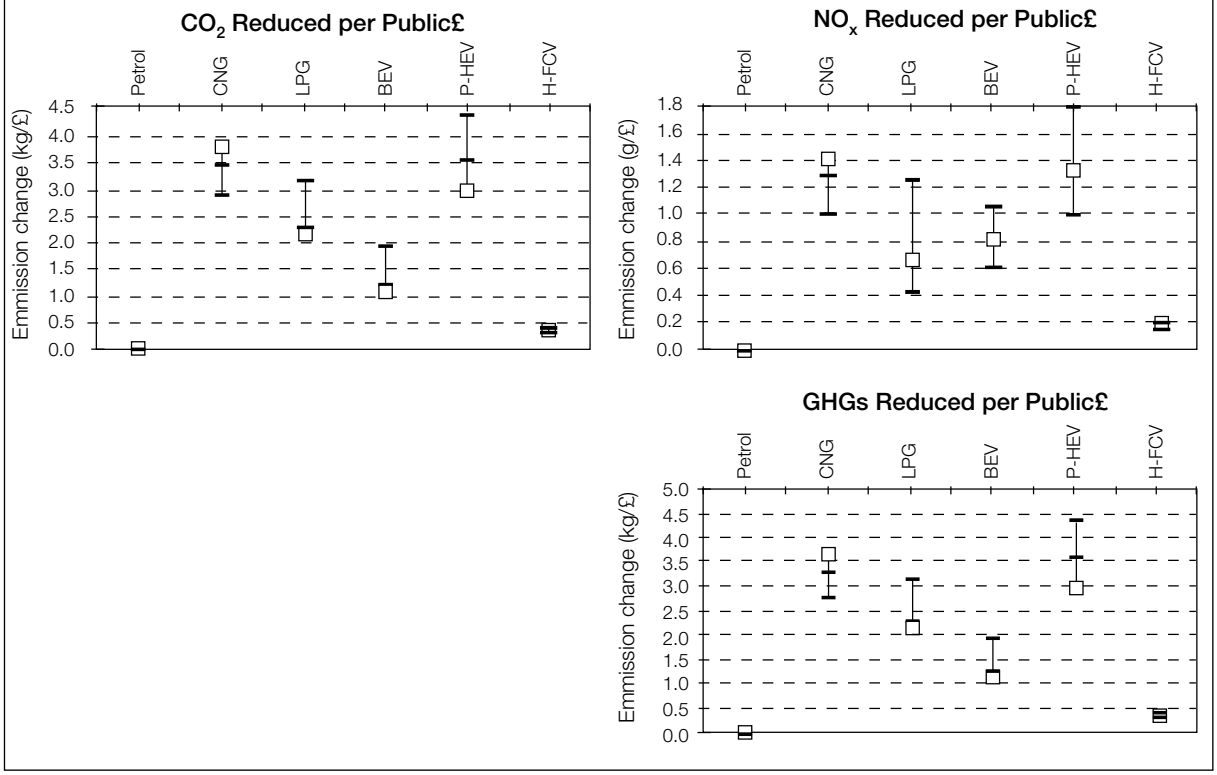
- For light duty vehicles, petrol hybrid electric vehicles (P-HEVs) should be supported on the basis of their current moderate cost-effectiveness in reducing CO_2, NO_x (compared to petrol) and a low to moderate cost-effectiveness in reducing PM_{10} (compared to diesel). Diesel hybrid electric buses should be supported on the basis of their moderate and high cost-effectiveness in reducing NO_x and CO_2 respectively. In addition, future trends for D-HEVs suggest a significant improvement in cost-effectiveness for reducing NO_x, PM_{10} and CO_2. In the future, diesel hybrid-electric buses are predicted to be the most cost-effective option for reducing NO_x and CO_2.

- Fuel cell vehicles offer the promise of zero or very low vehicle emissions, with performance and range equal or better than conventional vehicles. However, at present they are not a cost-effective option. Costs associated with production will have to be significantly reduced and issues related to fuel infrastructure will have to be solved before this technology can be a cost-effective solution to reducing local and global emissions.

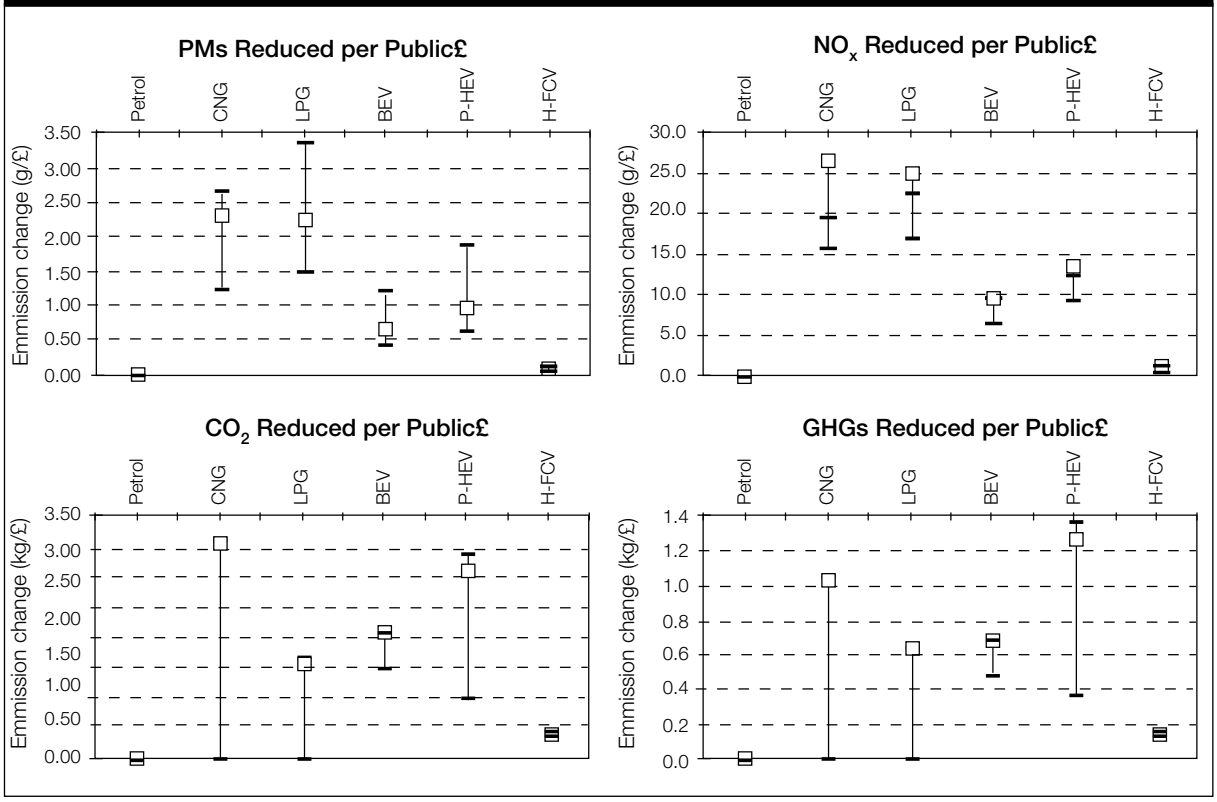
Charts C1–C3: Car Year 2000 – Cost-Effectiveness Analysis (Petrol Baseline)



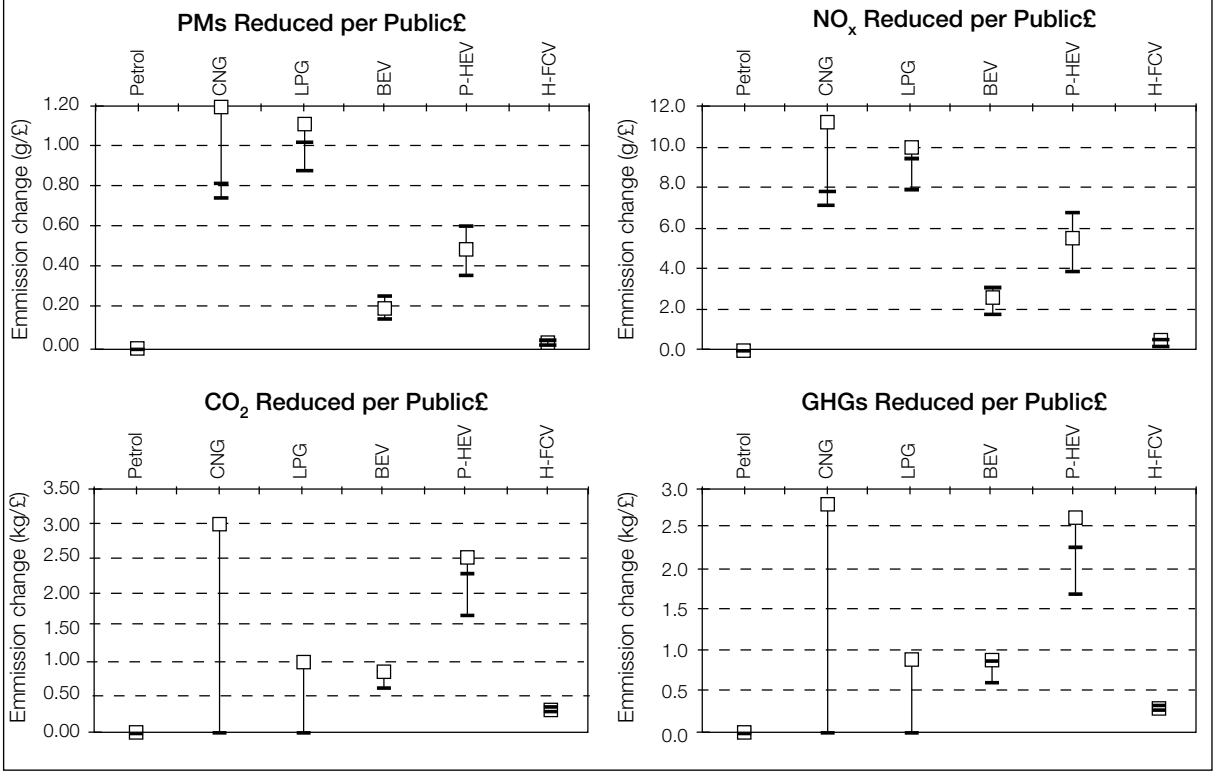
Charts C4-C6: **Car Year 2005 – Cost-Effectiveness Analysis (Petrol Baseline)**



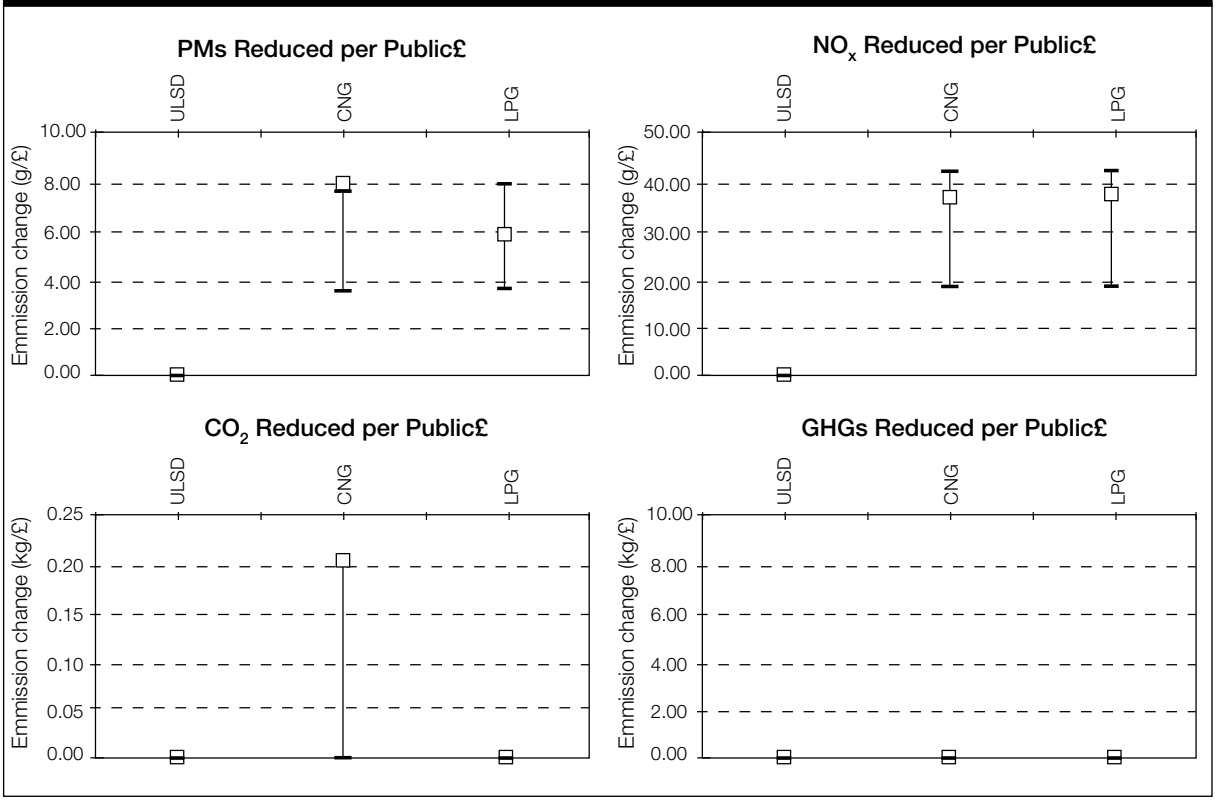
Charts C7–10: **Car Year 2000 – Cost-Effectiveness Analysis (ULSD Baseline)**



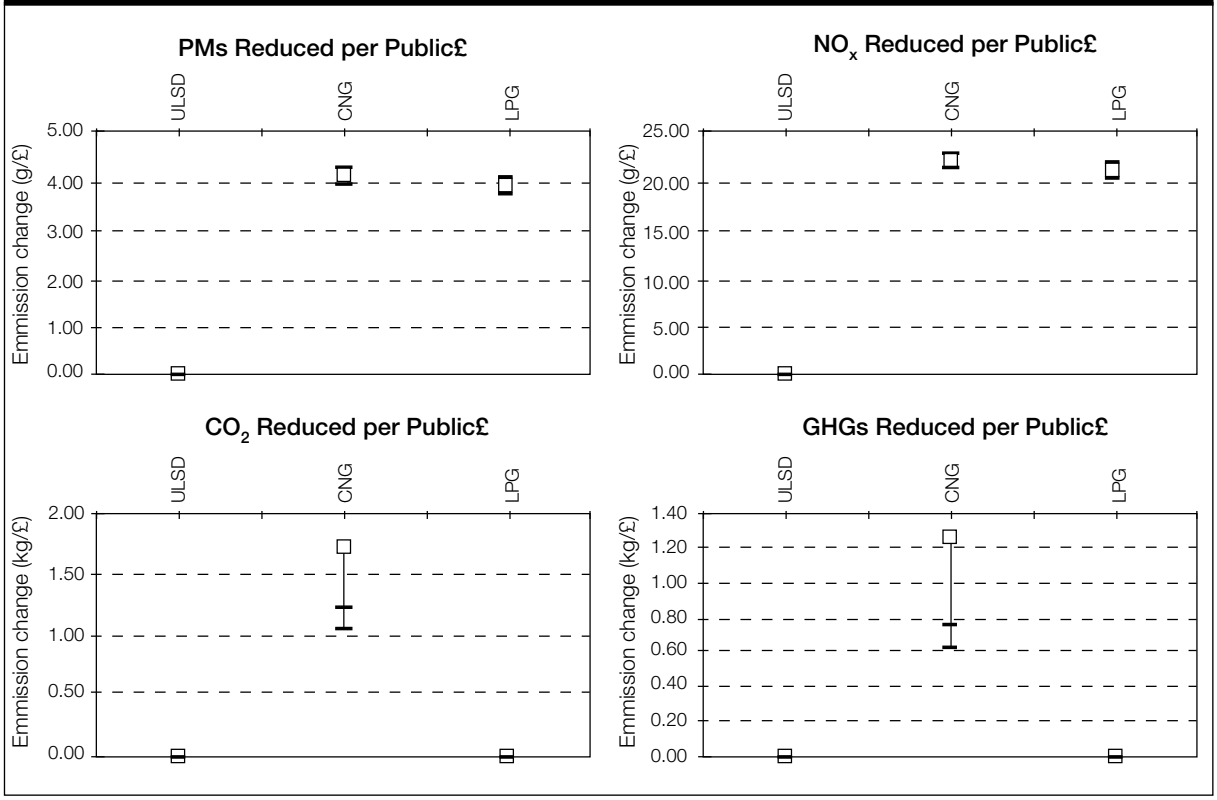
Charts C11–14: **Car Year 2005 – Cost-Effectiveness Analysis (ULSD Baseline)**



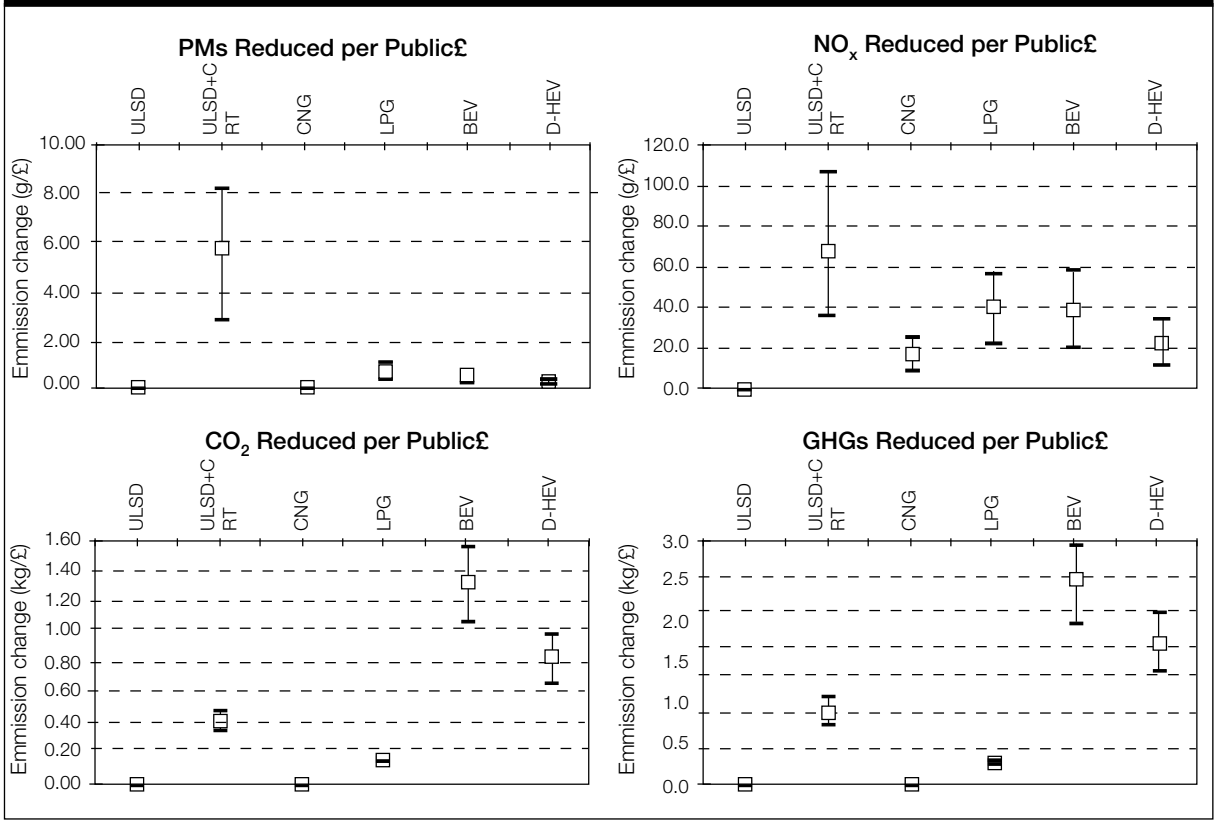
Charts C15–C18: **LDV Year 2000 – Cost-Effectiveness Analysis (ULSD Baseline)**



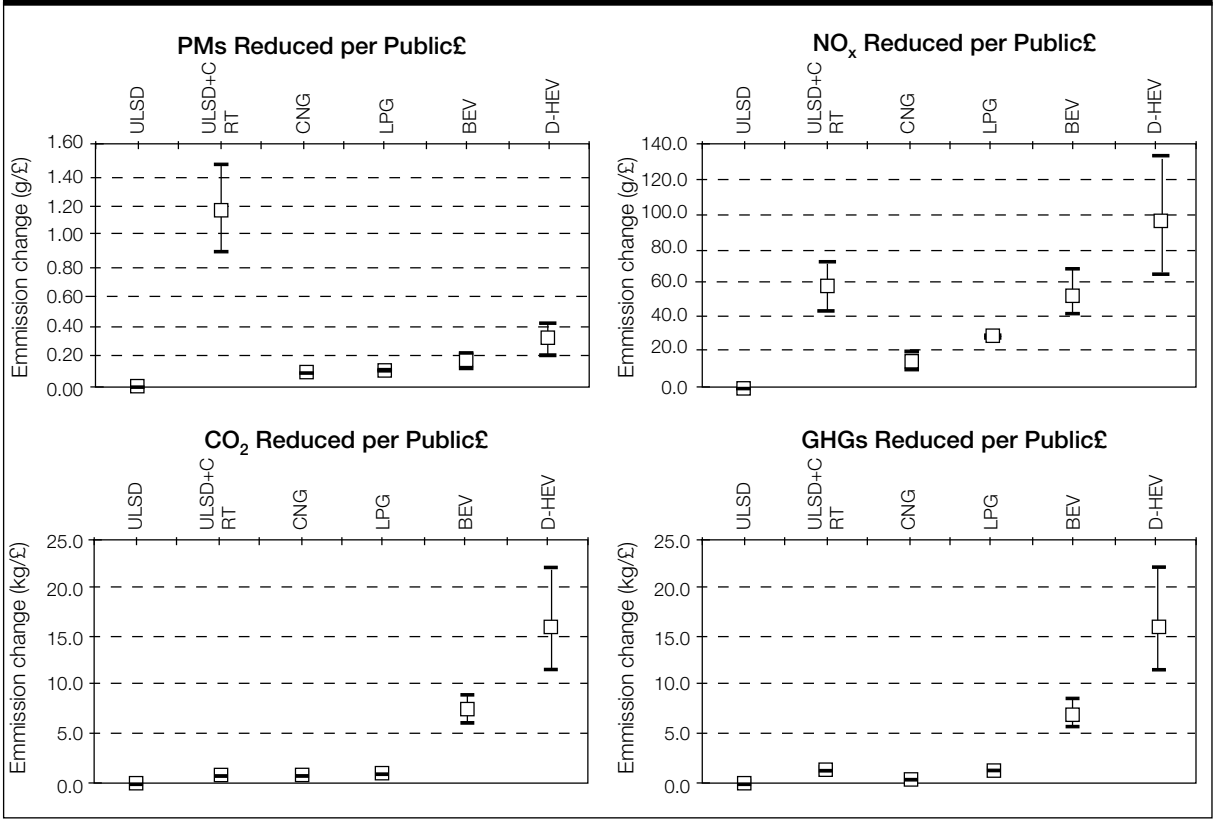
Charts C19–C22: **LDV Year 2005 –Cost-Effectiveness Analysis (ULSD Baseline)**



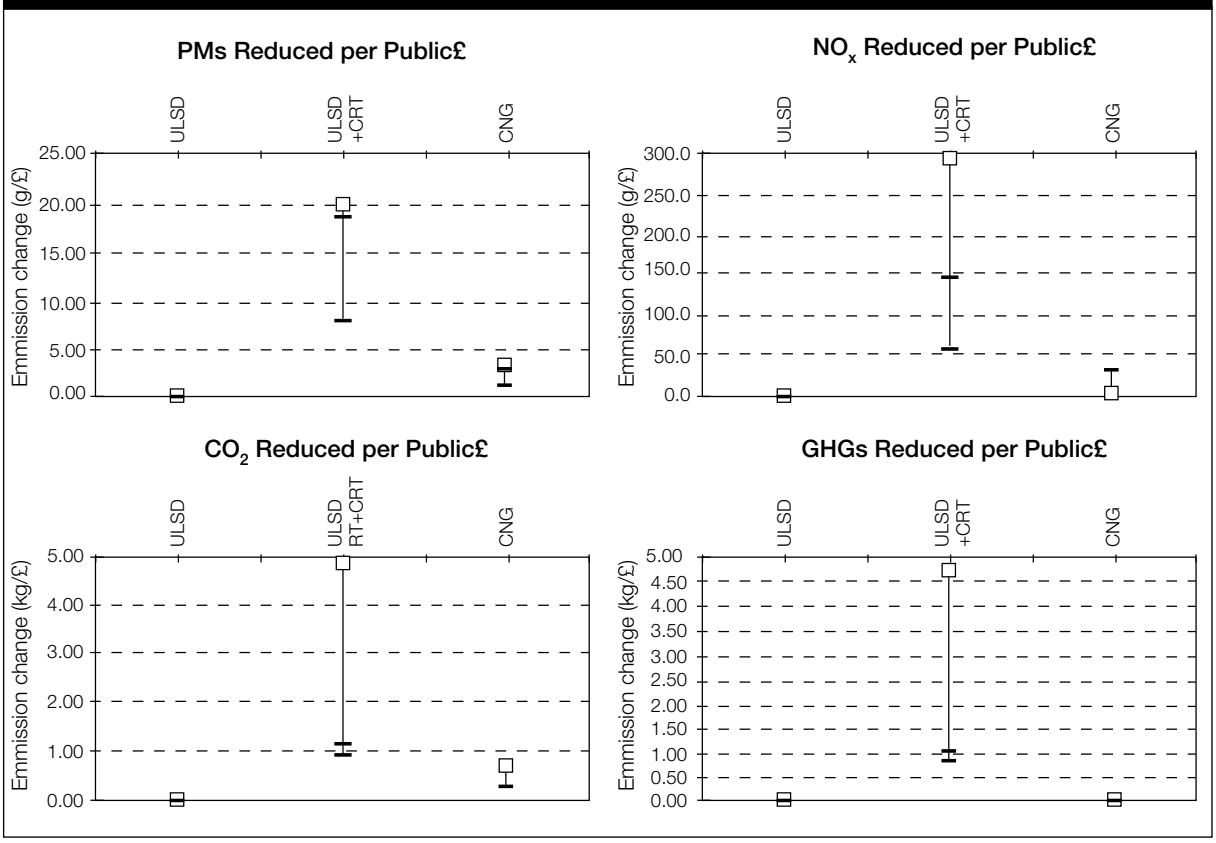
Charts C23–C26: **Bus Year 2000 – Results of Cost-Effectiveness Analysis**



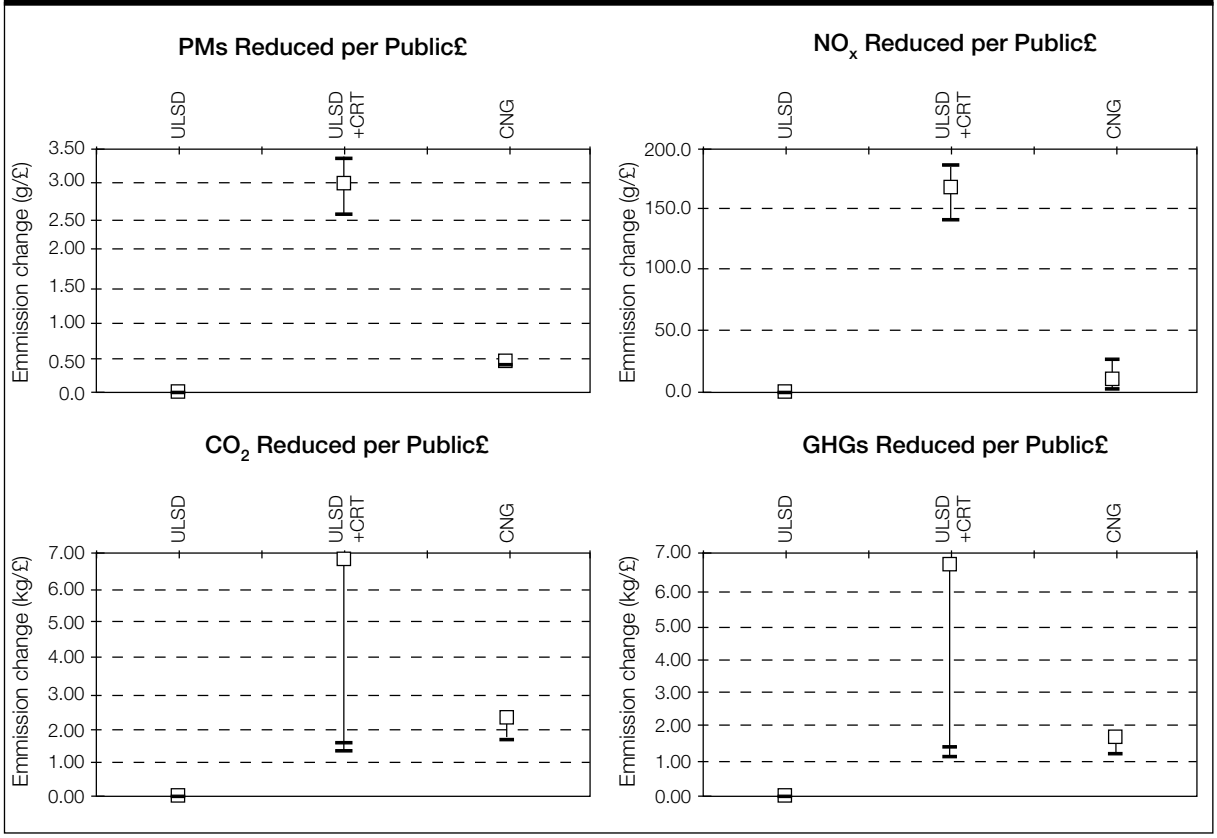
Charts C27–30: **Bus Year 2005 – Results of Cost-Effectiveness Analysis**



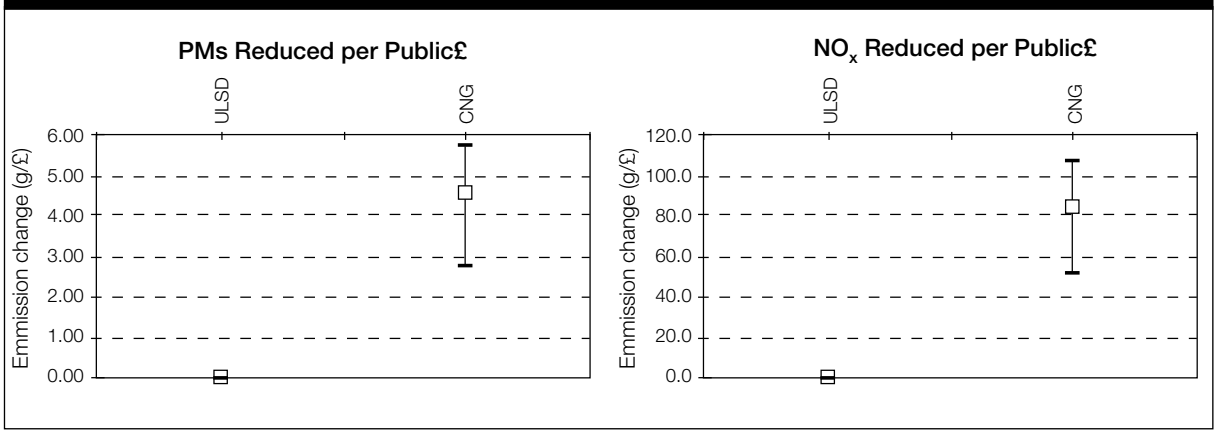
Charts C31–C34: **Rigids Year 2000 – Results of Cost-Effectiveness Analysis**



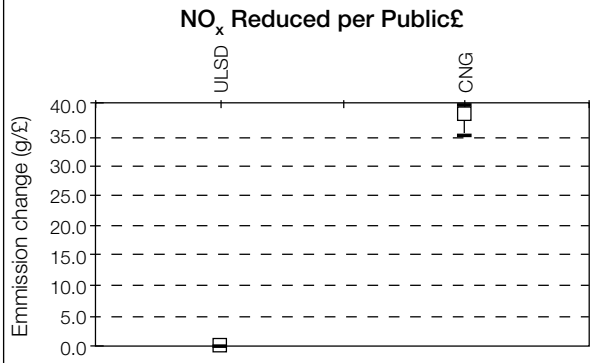
Charts C35–C38: **Rigids Year 2005 – Results of Cost-Effectiveness Analysis**

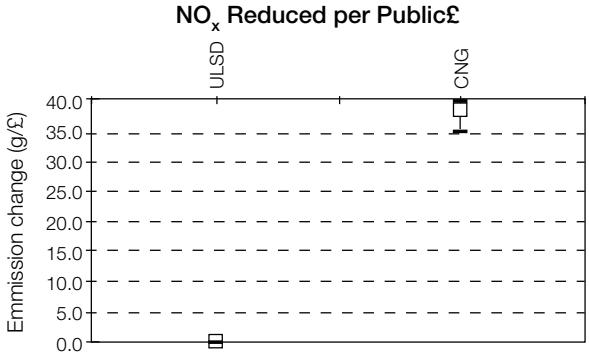


Charts C39–C40: **Artics Year 2000 – Results of Cost-Effectiveness Analysis**

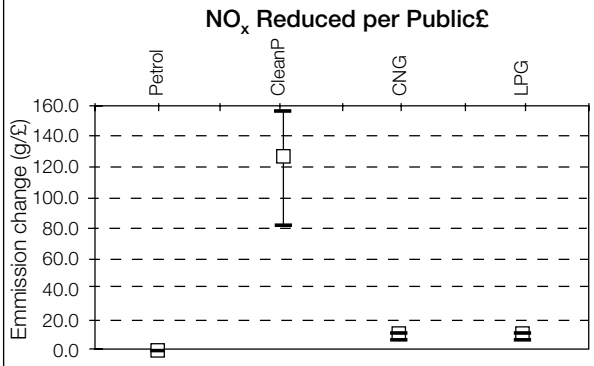


Charts C41–C42: **Artics Year 2005 – Results of Cost-Effectiveness Analysis**





Charts C43: **LDV Year 2000 –Cost-Effectiveness Analysis (Petrol Baseline)**



Barriers to the Introduction of Cleaner Fuels and Vehicles

Introduction

As with all new technologies, there are always factors which act as barriers to their introduction. Even if a new invention is welcomed by all concerned, there are often manufacturing or technical problems that must be refined. If a product aimed for market introduction, mass-production processes must be developed and the product marketed.

Most innovations experience further barriers at early stages of diffusion. These may arise due to dis-economies of scale, low market awareness or competition from existing established technologies. In most cases all these factors will act to inhibit the introduction of the new technology.

The processes by which new innovations become commonplace have been extensively researched and documented. Research groups which have focused particularly on transport innovations include the research project **Strategic Niche Management (SNM) as a Tool for Transition to a Sustainable Transportation System Project** (May 1996 – October 1998). The project was supported by the European Commission (DG XII), within the area Human Dimensions of Environmental Change of the RTD Programme Environment and Climate. The focus of the study was to investigate measures to overcome the under-utilisation of more sustainable transport technologies (SNM, 1998).

The SNM project examined how niches for alternative transport technologies have been created and managed by various actors, and how different promotional measures have contributed to the wider diffusion and development of new transport technologies and systems by building upon these niches. The approach differs from the more traditional 'technology-push' approach by actively encouraging the input knowledge and expertise of users and other actors into the technology development process to generate *interactive learning processes and institutional adaptation*.

A current European Project which is investigating the barriers associated with new road transport technologies is the **UTOPIA Project**. This project is supported by the European Commission and is administered in the UK by the Energy Saving Trust on behalf of the Directorate General for Transport (DG VII). The main objective of the UTOPIA project is "to provide decision-makers with the necessary tools, methods and guidelines for hastening the market introduction of the most appropriate transport solutions based on new propulsion systems" (Utopia, 1999). The scope of UTOPIA is road-based vehicles and urban light rail for passenger and freight transport used within urban applications in the time period 2000-2015.

Generic Barriers

The **IEA Report "Implementation Barriers of Alternative Transport fuels"** gives a review of the barriers faced by new transport technologies, their relative importance as well as possible solutions (IEA, 1999). The barriers discussed include:

Table C1: Barriers Which Can Impede the Introduction of New Vehicle Technologies	
Technical Barriers	• Fuel production barriers • Vehicle production barriers • Fuel infrastructure barriers • Fuel use barriers • Vehicle use barriers
Economic Barriers	• Capital vehicle costs • Capital infrastructure costs • Fuel costs • Non-fuel operating costs
Political & Regulatory Barriers	• Legislation and institutional barriers • Safety and environmental barriers
Social Barriers	• Organisational acceptance factors • Public acceptance factors

In the early stages of marketing a new fuel of limited vehicle product availability can hinder the wider diffusion of the product. This barrier can occur for alternative products which have a high yet unrealised market potential.

The following table summarises the generic barriers experienced by new fuel and vehicle technologies:

Table C2: Specific Barriers Which Can Impede the Introduction of New Vehicle Technologies

Generic Barrier	Details	Examples
Barriers related to fuel production	• Low refining capacity • Restricted fuel distribution • Minimum fuel demand is required	**Cleaner petrol** would reduce vehicle emissions from unleaded petrol vehicles. However, only a small number of forecourts currently make cleaner petrol available.
Barriers related to vehicle production	• Small-scale production • Low consensus of design solution	**Hybrid-electric** – although the Prius petrol-hybrid is selling in significant numbers in Japan, as yet no hybrid vehicles are commercially available in the UK. This will change in 2000 with the launch of two petrol-hybrid cars. In addition, there is no consensus about the optimum design.

Table C2: **Specific Barriers Which Can Impede the Introduction of New Vehicle Technologies (continued)**

Generic Barrier	Details	Examples
Barriers related to fuel infrastructure	In the early stages of marketing a new fuel, limited refuelling infrastructure can hinder the wider diffusion of the product. • Low number of re-fuelling points • Low regional coverage • Low public access to refuelling points • Restricted locations of refuelling sites	**LPG and CNG** – these alternatives already show good market potential. But, the low number of publicly accessible refuelling points (and low national coverage) has the potential to limit the expansion of these fuels, particularly for CNG due to the relatively high cost of refuelling equipment.
Barriers related to fuel use	Technical problems with cleaner vehicles can arise in connection with fuel use. New fuels may experience problems during fuel production, distribution, refuelling or when in use on-board the vehicle. • Fuel variability • Slow refuelling time • Awkward refuelling method • Problems during vehicle operation	**Cleaner diesel** – vehicles using ULSD standard diesel fuel experience higher than expected fuel consumption for vehicles running on fuels close to minimum standard for density and viscosity (see Case Study 1).
Barriers related to vehicle use	For new vehicle types, significant technical problems can emerge during vehicle production and vehicle operation. • Reduced performance compared to conventional vehicles • Reduce payload and/or cargo space • Low reliability of retrofit vehicles • Not enough maintenance people trained	**Battery EVs** – have a range which is significantly less than conventionally fuelled vehicles. **BEVs and NGVs** suffer from weight-payload restrictions due to the extra weight of the fuels systems which they require.
Increased Vehicle Capital Costs	Increased vehicle capital costs can inhibit the introduction of alternative road transport technologies. These arise from the new investment required for production and also to the economics of small scale production. • High price of OEM vehicles • Additional costs of conversion	Most alternative vehicles are more expensive than conventional vehicles. This is particularly true for **electric drive train** technologies and **heavy-duty dedicated gaseous fuelled vehicles**.

Table C2: Specific Barriers Which Can Impede the Introduction of New Vehicle Technologies (continued)

Generic Barrier	Details	Examples
Increased Infrastructure Costs	Capital costs associated with new infrastructure can inhibit the introduction of alternative road transport technologies. This can result in a low level of infrastructure provision and a reduced market demand. • Investment costs in infrastructure	New **CNG** infrastructure is significantly more expensive than conventional fuel refuelling systems. The cost of small-scale CNG refuelling systems range from £2000 (for two vehicles slow-fill) to around £250,000 for a system which can fast-fill a fleet of 15–20 buses.
Increased Fuel Costs	High alternative fuel costs can inhibit the introduction of alternative fuels and can affect and reduce initial market demand. • High fuel production costs (before taxes and subsidies) • High fuel pump price (including taxes and subsidies)	**Cleaner petrol** – cleaner petrol grades retail at 2-3p/litre more than ordinary petrol. The market for cleaner petrol would be greatly assisted by reducing pump price to the same level or less than ordinary petrol. This has shown to be effective for supporting cleaner diesel.
Increased Non-fuel Operating Costs	Increased operating costs are also likely to inhibit the introduction of new fuels and vehicle types. These may involve: • Increased maintenance costs • Poor/uncertain residual value of vehicles • Reduced revenue due to reduced payload	Heavy-duty **CNG** vehicles have a 1 tonne payload penalty. This increases overall costs as revenue income from freight delivery is reduced.
Legislation and institutional barriers	Although regulation is often essential for the assistance of new technologies onto the commercial market, dated or inappropriate legislation can greatly hinder the widespread use of new fuels and vehicle types. • Restrictions which mitigate against the use of alternatively fuelled vehicles or fuel • Non-existent standards and regulations • Need for tighter existing standards	New, **gaseous (and petrol) fuelled vehicles** will be required, from 2000, to fit On Board Diagnostic systems to record any emission control malfunction. This is 3 years ahead of the similar requirement for diesel fuelled vehicles and will provide an additional barrier to development of gaseous fuel markets.

Table C2: **Specific Barriers Which Can Impede the Introduction of New Vehicle Technologies (continued)**

Generic Barrier	Details	Examples
Safety and environmental barriers	While new technologies must be tested against existing safety legislation, they may be associated with different safety concerns. Even if risks are reduced overall, knowledge of changes in safety considerations require retraining operators and may require new monitoring equipment and procedures. • Risks associated with fuel handling • Risks associated with vehicle technology • Risks during vehicle operation	**Hydrogen fuel cell vehicles** have been successfully demonstrated since the 1960s. However, if large number of vehicles were to be fuelled by hydrogen, new legislation may be required to ensure safety during operation and refuelling.
Organisational Acceptance Factors	Social barriers can significantly hinder the adoption of new technologies. This may arise from the reluctance of manufacturers and suppliers to fully appreciate the advantages of new technologies and the government support available. • Non-recognition of advantages • Resistance of traditional fuel producers • Lack of information on AFVs • The need for retraining of personnel	In France, the predicted growth of **LPG and BEVs** has resulted in the increased demand for retrofit and maintenance of the vehicles. In 1997, there were only 200 LPG technicians and two schools where this can be learned (IEA, 1999). For, those working with BEV technology, a centre dedicated to BEV systems has been set up at Cergy, north of Paris (SNM, 1998).
Public acceptance factors	Social barriers can significantly hinder the adoption of new technologies. A low knowledge base and a resistance to change among consumers can also limit the up-take of alternative fuels and vehicles. • Non-recognition of advantages • Lack of consumer confidence in performance of AFVs • Low image or appearance of an AFV • Lack of information on AFVs	In a UK pilot study of public understanding, **only battery EVs and 'gas buses' were widely known**. Other vehicle types such as hybrids and fuel-cells were virtually unknown to the public. This issue will need to be addressed by promoters of AFVs if new vehicle types are to be effectively marketed in the UK in the near future (Lane, 2000).

Particular Barriers

As each of the cleaner road vehicle technologies considered in this report is at a different stage of development and introduction, and as each has its own particular barriers which affect its market introduction, the following sections describe in more detail the barriers involved for each of the options considered. To simplify the description of the most significant barriers associated with each option, fuels and technologies have been grouped where similar barriers apply.

Therefore, the barriers are discussed as follows:

- Cleaner conventional fuels.
- Gaseous fuels – LPG and CNG.
- Battery Electric Vehicles.
- Hybrid and Fuel Cell Electric Vehicles.

CLEANER CONVENTIONAL FUELS (PETROL AND DIESEL) – BARRIERS

Technical

The main technical barrier which impedes the introduction of cleaner petrol is the need for additional refining. The extra processing required is either achieved by adopting a more severe refinery operation or by investing in additional refinery facilities.

In the future (beyond 2005), there may be a growing demand for fuels with levels of sulphur well below the sulphur content of ULSD and 20005 petrol. Sulphur limits below 30 ppm and perhaps as low as 10 ppm may be required to assist the introduction of exhaust after-treatment systems. For example, the performance, catalysts and CRT systems are all severely affected by the use of high sulphur fuels.

Infrastructure

Currently, cleaner petrol is only available at a small number of forecourts. Further co-ordination by fuel suppliers to arrange distribution agreements to improve fuel availability is needed. The introduction of cleaner petrol may be hindered initially where limitations of forecourt space and tankage exist. This may deter some retailers making both conventional and cleaner grades available in parallel. They may prefer to retain their conventional grades or make a complete conversion to cleaner petrol.

Economic

With higher refining costs and low demand from consumers, there is little incentive for suppliers to make the fuel available. Hence, one barrier to the introduction of cleaner petrol is the initial resistance of refiners to make the necessary investment. Refiners' resistance is also based on the lack of necessary segregated storage, distribution and pumps.

At present, there is also a lack of fiscal incentives to encourage use of cleaner petrol from consumers. Current rates of fuel duty on cleaner petrol grades are often 2-3 p/litre more than ordinary petrol. With higher pump prices and low availability, there is no incentive for the public to purchase the fuel.

Political and Regulatory

The main political barrier is the lack of Government provision of a fuel duty tax incentive to promote cleaner petrol. A fuel duty differential of around 2p/litre would result in price parity between cleaner and ordinary grades. This measure has already been used to support the introduction of ULSD.

Although all cleaner diesel comply with existing BSEN 590 and ULSD standards, (in a small number of cases) some grades give poor vehicle performance and higher than expected fuel consumption (up to 10%). This appears to occur when vehicles are run on fuels close to minimum standards for density and viscosity allowed.

A further problem that can occur with the use of ULSD is that the range of aromatics in the fuels marketed is appreciably greater than in what was called 'standard' diesel. This can lead to external leaks of diesel from their fuel injection pumps. Vehicles which are run on consistently high or low aromatic diesel do not experience this problem. This problem would be avoided if the range of aromatics allowed by the specification for ULSD was reduced.

Social

There is a low level of public awareness of the both the existence and potential benefits of cleaner petrol. Anecdotal evidence suggests that the public are confused by the increasing number of petrol grades available on the market. This is not helped by the variation in product names under which cleaner petrol has been sold.

GASEOUS FUELLED VEHICLES (CNG AND LPG) – BARRIERS

Technical

Due to natural gas' low energy density, NGVs require bulky storage systems. This results in a vehicle which has reduced payload capacity. For equivalent vehicle range, a CNG bus would require approximately 5 times the storage volume and have a weight penalty of 800–1200 kg.

Dedicated LPG vehicles require a slightly larger fuel tank (1.4 times) to have a vehicle range equivalent to conventional vehicles. Due to the need for pressurised storage, the system has an associated weight penalty (a single-decker bus requires an extra 250 kg for equivalent range). This may be accompanied by a slight reduction in payload space or passengers carrying capacity.

Refuelling with natural gas is somewhat different from the refuelling gasoline vehicles. Refuelling buses with a fast-fill CNG system typically takes 10 to 15 minutes although faster installations are on the market. For private and company cars a long refuelling time may be considered unacceptable for forecourt refuelling (IEA, 1999).

Where after-market conversion kits (to bi-fuel LPG or CNG) are used, there has been some evidence of unreliability and poor vehicle performance. A number of products not built to the best standards have, in some cases, produced worse emissions than petrol or diesel. In Holland, it has been estimated that 50% of problems with LPG vehicle performance was due to poor conversions (IEA, 1999). However, with newer kits currently available (which include those accredited by the *Powershift* Register – see Case Study 11), this is much less of a problem in the UK.

Economic

One of the main barriers to the use of gaseous fuelled vehicles is their high capital cost. Dedicated vehicles remain more expensive to build due primarily to diseconomies of scale rather than inherent technical barriers. Additional costs range from £1,700 for a bi-fuel car to an extra £30,000 for a dedicated CNG bus. For LPG vehicles, the costs range from £1,000-£1,500 to convert a car or small van to £25,000 more for a new state of the art dedicated LPG powered bus.

Capital subsidies from Powershift and the current level of fuel duty, do result in private lifetime costs of LPG and CNG being comparable or cheaper than conventional vehicle operation for light-duty vehicles. However, there remains the high capital required to invest in new vehicle technologies. This barrier is especially significant for heavy-duty vehicles. In addition, the high capital required for each refuelling station represents a significant barrier for fleet operators wishing to switch to natural gas in particular.

The favourable fiscal treatment toward LPG for automotive purposes in recent years has been welcomed, but the UK excise duty on this fuel is still amongst the highest in Europe. In many countries, the fuel duty on gaseous fuels in already at the minimum of 8 p/kg allowed by EU regulations.

Although the fuel duty rebate for buses on qualifying PSV routes is 100% for gaseous fuelled vehicles, a rebate of around two thirds of the duty paid applies to diesel, which reduces the economic advantages of CNG and LPG fuels.

Infrastructure

One of the main barriers is the low number of publicly accessible NG and LPG refuelling points. Gaseous fuels are not likely to be included on a wide spread basis in filling station development until there is a significant upturn in the demand for LPG (i.e. increased vehicle numbers). However, the reverse is also true, vehicle numbers will depend on the availability of an extensive fuel network.

Though the UK has the advantage of there being an existing national NG pipeline grid, at present there are only around 24 CNG filling stations. These are mostly concentrated in the Midlands and the South East, but the number and geographic spread is expected to grow substantially. Even though several companies are installing new LPG refuelling points, there are only likely to be around 500 by the end of the year 2001.

In the view of the NGVA, developing an adequate national fuel infrastructure is now considered more of an issue than the provision of low fuel duty rates. There needs to be a strategic implementation of infrastructure with a view to future expansion. Already, some NGV fleets are having to expand facilities at further cost (see Merton – see Case Study 7) (NGVA, 1999).

When retailed through service stations forecourts, the margin the retailer receives from selling LP gas is similar to petrol and diesel. However, as sale volumes are low, retailers and oil companies find it difficult to justify the capital investment involved. The key factor is return on capital employed which is sales volume and margin related.

Political and Regulatory

Lack of standards (for storage cylinders, on-board systems, refuelling connectors and fuel stations) has in the past been a barrier for NGVs. For example, underdeveloped standards for cylinders has inhibited the entry of new lightweight aluminium and composite cylinders. The development of NGV equipment standards has been a key priority of the European NGV industry. This has led to agreed specifications that will form the forthcoming CEN Standards due for early 2000.

At present, for UK use, LP autogas and LPG vehicle construction standards do not present a barrier. However, parallel development of LPG as a road fuel across Europe needs to be considered for the medium-term. European Standardisation across Europe is an issue which affects the use of LPG vehicles for trans-national haulage. LP Gas composition varies considerably and is allowed by the current European Standard automotive LPG standards (EN589). Standardisation would enable vehicle manufacturers to optimise vehicle performance for the standard fuel in use.

Most of the hydrocarbon emissions from NGVs are methane (as much as 85%) which does not react in the atmosphere to create ground-level ozone (smog). Currently, the Euro Vehicle Emission limits contain no reference to standards for non-methane hydrocarbon (NMHC) for light-duty vehicles (as is the case for heavy-duty engines). As a result, an important benefit of light-duty NGVs continues to be unrecognised within European legislation.

The weight penalty associated with CNG (and other alternative fuels) reduces the pay-load that can be carried by the vehicle. This can reduce revenue for the operator who may already be working within tight economic margins. To overcome this barrier, vehicles with a greater payload capacity are often purchased. However, the vehicle is then incurs a higher rate of vehicle excise duty.

Social

Lack of awareness of fleet operators is a major barrier. Fleet managers are very familiar with diesel and any new fuel (even gasoline) would require major changes to their working conditions and procedures e.g. mechanics would not be able to smoke; maintenance schedules would have to be changed, and new health and safety standards would apply) (IEA, 1999).

There is a short-term problem with the public perception of safety problems in terms of the explosive nature of gas. However, this is already declining as the public becomes more familiar with the concept of NGVs and experience an increasing number of vehicle demonstrations and trials around the country (IEA, 1999). Public resistance to LPG use is likely to be lower than for NG as LPG has been extensively used for a number of years in the private car market. Users were encouraged by LP gas' low fuel price during the 1970s and early '80s.

Although CNG and LPG presents no increased risks, their use presents different handling due to the properties of the gases involved. These will require education programmes by vehicle users and maintenance crews. The main safety consideration for LPG is that, in the event of a gas spillage, the gas tends to sink to the lowest level of its surroundings such as drains pits or within a semi-enclosed vehicle space. Some countries ban LPG vehicles from underground car parks to prevent any risk of gas build-up.

BATTERY ELECTRIC VEHICLES – BARRIERS

Technical

Battery electric vehicles have severely limited applicability due to their short range. Typically, vehicle range for per charge is 70-90 km using existing battery technology. This means that the use of BEVs has to be carefully matched to the use of the vehicle. However, given a predictable duty cycle, BEVs are well suited to urban road conditions.

Vehicle performance is also below that of conventional vehicles. For most commercially available BEVs, (though certainly not all), acceleration is reduced. For a electric car derived van, payload may be reduced by up to 300 kg due to the extra weight of the battery system.

For slow charging units, recharging times pose a potential barrier for the use of BEVs. Typical recharge times being 6-8 hours. For the private motorist slow overnight charging will probably be the preferred option. Fast chargers are available, but with an associated cost penalty; either for the charging unit or the vehicle if an 'on-board' charger is used.

Economic

One major barrier to the uptake of BEVs is the high vehicle cost. This is primarily due to the high cost of the battery. The result is a vehicle which can be 50–100%, more expensive than its conventional counterpart. Often, the vehicle is purchased without the battery, which is leased on a monthly basis.

An advantage afforded by BEVs is that fuel costs per km are low due to the high efficiency of the vehicle. For a small car sized BEV, fuel costs are less than 1 p/km. Though leasing the battery reduces the up-front capital costs, the effect is to increase the 'operating' costs to a point where fuel cost savings are diminished, so reducing one of the main advantages of battery vehicles.

Taken overall, the DETR Model shows that lifetime public costs are significantly higher than conventional vehicles (car and bus). Even with Powershift funding, from a lifetime private perspective, battery electric cars and buses are around 10–15% more costly. Therefore, the increased costs of BEVs continue to act as a significant barrier to their introduction.

Infrastructure

UK national or urban fast re-charging infrastructure has not yet been developed. This is partly due to the fact that a large investment is required while the final market or need is not yet known. However, the lack of a publicly accessible fast-recharging network may inhibit the BEV market.

Commercial users require fast charging points to extend the daily range of vehicles. These rechargers could be sited at depot bases or be road-side posts for commercial and public use.

From private motorists point of view, fast-chargers are seen to be required to allay driver's fears of running out of fuel. However, the French experience is that these chargers are rarely used by private BEV users.

Most important for the private motorist is the introduction of home slow charging points. However, in built-up urban areas, where there is no access to a garage, the siting and associated administrative procedure required can be problematic. Furthermore, the use of

BEVs requires a change in owner behaviour required, i.e. fitting recharging into daily schedule.

As recharging systems vary from one vehicle to another, not all BEVs are able to refuel at the same outlet. For instance the Peugeot 106 is not compatible with the Wavedriver fast-charging system. Within Europe, there are several inductive recharging designs in addition to a number of conductive systems. Furthermore, the charging systems and connectors currently manufactured for commercially available BEVs are considered technically sound but too expensive for the long term.

Social

There are still many public mis-conceptions regarding the use of modern BEVs. This relates to the performance of modern vehicles and their potential to do a wide range of duties and journeys with existing technology. Additionally the vehicles are still tainted with negative perceptions linked to milk-floats, invalid carriages and the Sinclair C5. Also, the public may not be aware that even when power station emissions are taken into account, electric vehicles still result in significant net reductions of most pollutants.

HYBRID AND FUEL CELL ELECTRIC VEHICLES – BARRIERS

Technical

Although Toyota have been marketing an HEV passenger car in Japan since the start of 1998 with much success, technical barriers which remain relate to the choice of hybrid technology option. There is still no consensus on whether series or parallel hybrid designs offer the best performance. In the long run, it may be that a number of hybrid designs will compete for hybrid sales. This may have the effect of limiting the cost savings associated with large scale mass production.

Fuel cell technology has some way to go before the advent of on-road fuel cell vehicles. Unlike hybrids, there is some convergence of fuel cell vehicle design. The PEMFC and alkaline fuel cell types are the main two fuel cell types to be seriously considered by the automotive industry. The solid-polymer PEMFC is favoured by most and is being actively developed by Ballard Power Systems in conjunction with Ford and DaimlerChrysler for use in a commercial vehicle by 2004.

On-board storage of hydrogen gas has presented a technological challenge to FCV design. A number of alternatives to on-board storage of gaseous hydrogen are technically possible; compression or liquefaction of the gas, the use of hydrides which absorb hydrogen gas; and reformation of fuel on-board the vehicle to produce hydrogen on demand. However, all solutions have a range, weight or cost penalty associated with them.

On-board reforming of a hydrogen carrier also poses significant technical challenges. Indeed, there is as yet not even a consensus about which fuel should be used. Even if a petrol reformer was successfully developed, this would probably require the introduction of a new grade of petrol and associated infrastructure.

Economic

The main barrier to the introduction of HEVs and FCVs is high cost of vehicle production. Currently, all hybrid-electric vehicles are being sold at less than their cost price. Even with Powershift funding, on a lifetime costing basis, current HEVs are significantly more costly than conventional equivalents (by at least 13%). Therefore, the costs of the technology have

not reduced to a point where hybrid-electric vehicles can be widely introduced. It remains to be seen if increased production will reduce unit price.

The current costs of fuel cell vehicles are far higher than conventional vehicles. The current Ballard bus (PEMFC technology) costs 7 times the price of a diesel bus. Though the Necar passenger car under development is not intended for commercial sales at this stage, some commentators predict an increased capital vehicle cost when the vehicle is launched in 2004. However, DaimlerChrysler has stated that it intends to market the Necar at the same price as the conventional A-Class (IEA, 1999).

Infrastructure

Infrastructure changes required by the introduction of fuel cell vehicles would involve the addition of a new fuel infrastructure. As long as only very few hydrogen fuel cell vehicles exist, it will be extremely difficult to make a case for installing a new hydrogen or hydrogen rich fuel infrastructure.

If hydrogen were to be used and distributed in its gaseous form, modified natural gas pipes could be used. An extensive hydrogen pipeline network has been effectively used by the chemical industry in the Ruhr, Germany for many years. If natural gas is used a feed-stock for hydrogen production on-site, it can be piped using the existing grid and reformed where required. This would be most suited to depots for use with centrally refuelled fleets. Small natural gas reformer units are already commercially available.

With the use of on-board reformers, infrastructure changes would comprise the inclusion of a new liquid fuel at conventional fuel stations. This would most likely be methanol or a specially formulated ultra low sulphur grade of petrol (<10 ppm).

Political and Regulatory

Given the trade off between improved fuel economy of parallel hybrid systems and lower overall emissions of series hybrid designs, legislation may play a crucial role in favouring one system over the other. Also, the more stringent are the requirements for long zero-emission operation, the smaller will be the overall fuel economy and vehicle emission reductions. For FCVs, there exists very little legislation on safety, fuel tanks and other issues relating to hydrogen fuel cell vehicle use.

Social

A UK research pilot study in 1998 showed that very few members of the public had heard of hybrid-electric vehicle technology. When asked to list alternative vehicle types, out of a sample of 360, the words 'hybrid' was used by only 1 person and the words 'fuel cell' was used by only 3 people. As Toyota are planning to launch vehicles such the 'Prius' petrol-hybrid in Europe in 2000, and DaimlerChrysler are developing vehicles such the 'Necar X' fuel cell vehicle for launch in 2004, it appears that UK consumers quickly need to be made aware of the existence of these technologies before these vehicles can be effectively marketed (Lane, 2000).

Public acceptance research conducted by LBST in Germany showed that, in that country, hydrogen technologies enjoy a high level of acceptance among hydrogen bus passengers and among secondary level school students in Germany, all of whom are in favour of the further development of hydrogen technologies. Even though people see a certain danger of explosions in hydrogen technologies, the study does not reveal potentially severe acceptance problems.

Most importantly, the German study shows a general tendency towards higher acceptance of hydrogen technologies when people are in direct contact to them (LBST, 1999).

Table C3: Summary of Barriers for Alternative Fuels

Cleaner Petrol	• Restricted supply of cleaner petrol grades (<50 ppm sulphur). • Lack of fiscal incentives to encourage production and use of this fuel before 2005. • Required investment in refining capacity and in distribution agreements amongst fuel suppliers.
Cleaner Diesel	• Some diesel fuels which comply with the specifications for Ultra Low Sulphur Diesel as quoted by the 1998 Finance Act and/or comply with existing BSEN 590 Standards give poor vehicle performance. • Lack of incentives to encourage the uptake of less than 10 ppm sulphur diesel fuel.
Natural Gas Vehicles	• High capital cost of natural gas vehicles (for certain market sectors). • Lack of adequate natural gas refuelling infrastructure through all parts of the UK. • CNG storage tanks impose a vehicle weight penalty which reduces payload. • As emissions certification of light-duty vehicles is currently based on total hydrocarbons, this gives an unfair reflection of ozone forming potential, which for natural gas should be based on non-methane hydrocarbons. • OBD systems are currently required to be fitted to gaseous fuelled vehicles from 1st Jan 2000 (a delay in introduction has been allowed for diesel vehicles until 2003). No OEM is able to develop this system in the timeframe required. • Higher life-time private cost for the heavy-duty sector due primarily to increased capital costs which result from diseconomies of scale. • The current diesel rebate scheme for bus operators acts contrary to fiscal measures used to support NGVs. The rebate therefore, reduces the incentives for bus operators to invest in NG buses.

Table C3:**Summary of Barriers for Alternative Fuels**	
Liquefied Petroleum Gas	• High capital cost of liquefied petroleum gas vehicles (for certain market sectors). • Lack of adequate liquefied petroleum gas refuelling infrastructure through all parts of the UK. • OBD systems are currently required to be fitted to gaseous fuelled vehicles from 1st Jan 2000 (a delay in introduction has been allowed for diesel vehicles until 2003). No OEM is able to develop this system in the timeframe required. • Higher life-time private cost for the heavy-duty sector due primarily to increased capital costs which result from diseconomies of scale. • The current diesel rebate scheme for bus operators acts contrary to fiscal measures used to support LPG vehicles. The rebate therefore, reduces the incentives for bus operators to invest in LPG buses.
Battery Electric Vehicles	• High capital cost and limited supply of battery electric vehicles. • Limited vehicle range and performance as compared to conventional vehicles. • Reduced payload capacity as compared to conventional vehicles. • Lack of widespread publicly accessible re-charging infrastructure and over complexity of bureaucratic process to install road-side recharging points.
Hybrid Electric Vehicles	• High cost of hybrid-electric vehicles (as of start 2000). • Limited supply of hybrid-electric vehicles in the UK (as of start 2000). • Uncertainty about the optimum system design.
Fuel Cell Vehicles	• High capital cost of vehicles where available. • Lack of supply of vehicles in the UK. • Technologies not developed to mass-production standards. • Uncertainty about the choice of fuel (and hence infrastructure) used to deliver the hydrogen to vehicle.

SECTION D:

Case Studies: UK Experience with Cleaner Fuels and Technologies

1. UK Introduction of Cleaner Conventional Fuels

Contributors: Members of AUKOI and the Freight Transport Association

The following case study is the common position taken by members of the FTA and the Association of UK Oil Independents (AUKOI) of which Tesco, J Sainsbury and Safeway Supermarkets and Futura Petroleum Limited are members.

Cleaner diesels, and on a much smaller scale cleaner petrol, are already commercially available in the UK. Their market promotion has been assisted by the major Supermarket retailers and depot based fleet operators. For example, at Tesco outlets, ultra low sulphur diesel is now retailed at all of its fuel stations and the company would increase their sales of cleaner petrol if the product were supported by Government in terms of a preferential duty rate.

BARRIERS TO THE INTRODUCTION OF CLEANER CONVENTIONAL FUELS

It is important to note that as of January 2000, all diesel sold in the UK complies with the ULSD standard.

Futura see no significant technical barriers to the continuing use of cleaner diesel or the increased use of cleaner petrol. However, any development of the cleaner petrol market will involve conversion of existing facilities to cleaner petrol. The introduction of cleaner conventional fuels has and will continue to require label and point of sales changes and any work required to increase tankage capacity. In addition, further tanks, pumps, hose, nozzle and underground pipe-work will also require changing.

As typical forecourts have storage capability for only 4 grades of fuel, cleaner fuels will have to compete for forecourt space. ULSD is now well established and will replace all diesel sold by the end of 1999. Cleaner petrol on the other hand, still has to establish itself in the commercial market.

As oil companies have been reluctant to invest in UK refineries to enable them to produce cleaner petrol, at present, there is a significant lack of supply of this fuel in the UK. This has meant that the products have to be imported to coastal locations which has restricted supply to forecourts within economic distribution distance from these distribution points.

The major economic barrier (for both cleaner diesel and petrol) has been the higher production costs required to manufacture these higher specifications. The majority of the private sector will not pay more for clean fuels and therefore tax incentives are required to compensate suppliers via the widening of the duty differentials.

Here we see an example of a market start-up barrier (see Section C). The extra cost of producing this grade cannot be offset by economies of scale due to low demand. However, demand cannot be stimulated due to high cost. Government intervention, in the form of fiscal or regulatory measures is therefore required to help break this inhibitory cycle.

Profit margins for cleaner conventional fuels can be made comparable with their conventional counterparts by the introduction of preferential duty rate (ULSD) and/or by charging a higher retail price (as is the case with cleaner petrol).

MEASURES TO ENCOURAGE THE UP-TAKE OF CLEANER CONVENTIONAL FUELS

The success of the introduction of ULSD has shown the importance of fuel duty rates in stimulating the market. Initially this grade had to be imported and was only available through supermarket forecourts. However, since a preferential duty rate given to this grade, it is now widely marketed in the UK. The duty benefit given to ULSD has meant a sudden increase in availability from UK oil companies and has resulted in the roll out of this grade to all sites converted by the end of 1999.

The supermarkets and other organisations welcome the current duty incentives which have encouraged the production of ULSD and look forward to future incentives for cleaner petrol. Without the same treatment, cleaner unleaded petrol will remain a niche product. With an adequate duty preference, there could be a massive increase in the availability of this grade.

Futura, Tesco (and others) believe that, in time, a sustainable market for cleaner fuels could develop with a positive cost differential, but think that a fuel duty differential of 2 p/litre for cleaner petrol is required to ensure a small positive, or zero, price differential and a significant market up-take. This would stimulate both demand and supply (Tesco, 1999; Q8, 1999; Green*ergy*, 1999).

UK Refinery production of the new fuels requires stimulation and support through government tax incentives. Support must include prior notification in terms of Government strategy and the development of a standard specification for cleaner petrol. Clear guidance from Government in terms of policy direction and time-scales enables forward planning for commercial organisations so that required invest can be planned for and implemented.

THE NEED FOR TIGHTER STANDARDS FOR CLEANER DIESEL (FTA)

According to the FTA, many fleets are now using ULSD with reported changes in fuel consumption varying from zero to an increase of over 10%. There appears to be an unexpectedly large number of vehicles suffering between 5 and 10% increase in fuel consumption and, after investigation, these appear to be running on fuels close to minimum standard for density and viscosity BSEN 590.

This effect is confirmed by EPEFE testing which has shown that "reductions in fuel density decreases engine power output and increases volumetric fuel consumption. Variations in fuel viscosity (i.e. reduced density generally reduces viscosity) may accentuate the density effects on power (not necessarily fuel consumption), particularly in combination with distributor-type injection pumps" (ACEA, 1998).

The FTA therefore recommend that, for the above reasons, any move to reduce the minimum density or viscosity for diesel fuel must be resisted.

A further problem that has occurred with the use of ULSD is that the range of aromatics in the fuels marketed is appreciably greater than in what was called 'standard' diesel. A number of members of the FTA, including a very large fleet of ambulances, are experiencing external leaks of diesel from their fuel injection pumps.

Investigation has shown that this is due to the vehicles operating on a low aromatic ULSD when they had previously been operating on a comparatively high aromatic standard diesel. While using the high aromatic diesel, some of the aromatics were absorbed into the seals and these are now leaching out with the use of low aromatic diesel. The result has been shrinkage and, in the worst case, cracking of the seals. Vehicles which run on consistently high or low aromatic diesel do not experience this problem. Therefore, the FTA recommends that limits for aromatics should be quoted in BSEN 590 to remove the considerable problems on vehicles in service.

SUMMARY

Widening the duty gap between clean and regular fuels is an important mechanism to stimulate and facilitate the wider availability of cleaner road fuels. Legislative policy on tax differentials, used to kick-start and support the uptake of cleaner diesel has proved to be an effective lever which assisted the market up-take of low sulphur diesel fuels. However, the same support has not be given to cleaner petrol, the fuel duty of which is the same as for conventional petrol.

Futura, Tesco (and others) believe that a fuel duty differential of 2 p/litre for cleaner petrol is required to ensure a significant market up-take. This would stimulate both demand and supply (Tesco, 1999; Q8, 1999; Green*ergy*, 1999).

In the past, lack of clear policy guidelines, tax incentives and legislation by successive governments has delayed wider distribution of cleaner conventional fuels. Further support from the Treasury and HM Customs and Excise would be welcomed with regard to fuel duty tax incentives. Unless cleaner unleaded petrol is given the same support as ULSD, oil companies will not make it available until forced by legislation due to come into effect in 2005.

2. UK Introduction of LPG Vehicles

Contributors: Tom Fidell, Liquefied Petroleum Gas Association

The LP Gas Industry, OEMs and conversion companies are investing heavily in the development of the autogas market. The views contained in the following sections are based upon the assumptions that the Government will continue to provide the fiscal incentives necessary for this development.

Although considerable headway has been made in starting to establish this new emerging market, it is still in a very fragile and delicate state and could easily be blown off course by the wrong signal being sent from Government as a result of inappropriate Budget decisions. It should be noted that an autogas market did exist in the UK in the late 1970s but this died away through lack of Government commitment and support.

THE FUTURE OF LPG IN THE UK

The most common motivation for vehicle operators introducing LPG are, in order of importance; costs, local air quality, PM_{10}, NO_x, noise and CO_2. Costs are the main decision factor for all commercial, fleet operators and local authorities. Although these groups have an objective to reduce the environmental impacts of transport, the solutions must be 'green' at the lowest cost in preference to diesel and petrol.

The LPGA estimate that the market for LP Gas powered vehicles could grow from 7,000 at the start of 1999 to over 250,000 vehicles in 5 years time. In consumption terms, this will relate to increasing from around 3,000 tonnes to 300,000 tonnes of LP Gas over the same period. To start significant growth in this new market, the LPGV fleet must be increased by around 1,000 vehicles within the next year. This requires considerable commitment from all parties involved in developing LPG as a viable clean fuel.

The most significant growth sector for LPG vehicles is predicted to be car and LGV in urban areas with fleet users being predominant over private users. The LPGA does not see a significant increase in the bus market until fiscal measures make this a more economical option.

INFRASTRUCTURE

The expansion of LPG refuelling infrastructure is most likely to occur through publicly accessible forecourts, supported by a seed structure of depot based fuelling centres.

Over 300 depot based LPG facilities (not available to the public) have been installed by the industry and the main issue for each of these facilities is the relatively low number of vehicles using these depots. On average, the LPGA predict that there are less than 15 vehicles based at each depot. Depot based refilling will, however, remain an important element in the development of the automotive market.

As of mid 1999, there are around 200 refuelling sites which are open to the public but of these only around 20 are forecourt facilities. However, this situation is likely to quickly improve. For example, Shell UK aims to install 200 LPG refuelling points on their forecourts by 2001. A total of 500 (predominantly forecourt) sites is predicted by the year 2001.

BARRIERS TO THE TAKE-UP OF LPG

Technical barriers in the development of an infrastructure have in the main been overcome. The main barriers which remain are related to increased capital vehicle costs and the development of an extensive refuelling network with sufficient coverage. LPG is not likely to be widely available at filling stations until there is a significant upturn in the demand for LPG i.e. increased vehicle numbers. This is a typical 'market start-up' problem.

LPG vehicles either have to be specially designed or converted to run on LP gas and these costs need to be recovered from the savings in running costs. To convert a car or small van to run on LPG costs between £1,000–£1,500 when using the latest technology equipment. The cost of a new state of the art dedicated LPG powered bus is approximately £25,000 more than a diesel bus (although this would reduce significantly with increased sales volume).

Comparing the conventional diesel to LPG for a panel van and petrol to LPG for a car, the figures show that we have an almost break-even situation for the comparison with petrol for the car, but an additional cost of around £550 for operating an LPG powered panel van compared to diesel operation.

Although the fuel duty rebate for PSVs on qualifying routes is 100% for LPG, a rebate of around two thirds of the duty paid applies to petrol and diesel which reduces the economic case for LPG. The differential duty rate between LPG and ULSD is currently 12.3 p/litre when used for public transport and 47.2 p/litre when used for purposes other than public transport. Thus the bus market needs additional incentives to invest in cleaner technologies as aimed for by the Government's own transport strategy.

The favourable fiscal treatment toward LPG for automotive purposes in recent years has been welcomed, but the excise duty on this fuel is still amongst the highest in Europe. However, the key factor is not the actual rate of duty but the differential rate of duty on an equal energy basis between LPG and petrol. On this basis, the UK is still some way behind those countries who are encouraging the wider use of auto-LPG.

When retailed through service stations forecourts, the margin the retailer receives from selling LP gas is similar to petrol and diesel, but significantly less than provisions and car wash sales. The margin itself, therefore, does not hinder the development of forecourts refuelling points. However, as sales are so low, retailers and oil companies cannot justify the capital investment at present. The key factor is return on capital employed which is sales volume and margin related. This will naturally hinder the development of the network infrastructure.

A political barrier is that the Clean Air Policy promoted by the Government departments (most notably the DETR) is not mirrored by Treasury policy. There needs to be consistency in Government policy across all departments. The Government should also pursue a policy that reflects Clean Air policy and emission targets in a sustained fiscal policy which should favour lower emission fuels.

PROMOTIONAL MEASURES USED TO ASSIST THE INTRODUCTION OF LGVS

The most significant policy levers which will stimulate the wider development of an LPG infrastructure are:

- a positive Budget which favour the use of LPG in automotive applications;
- clear signals from the Government that LPG will receive long-term, support as a future clean fuel.

Excise duty on the fuel is the main fiscal measure and the differential duty between LPG and petrol/diesel needs to continue to increase until it is a viable option on economics alone. The 1996 report by the house of Lords Select Committee on Science and Technology entitled "Towards Zero Emissions for Road transport" recommended that excise duty in the UK is reduced to the EC minimum which equates to approximately 6.8 p/kg. As the present duty on gas is 15.0 p/kg, the LPGA urge the Government to move closer to the EC recommended minimum for a period of not less than 6 years.

The national and local Government measures that have so far assisted the development are tax and duty breaks and this could be further enhanced with a future concession on VED. A further incentive to overcome barriers would be to allow fleet operators to have a write down allowance in the first year of 100% (rather than the standard 25%) of the cost of converting a vehicle to gas. A 100% write-down allowance on the cost of the infrastructure fuel facilities would also be of assistance.

To offset the increased costs of LPG vehicles and conversions, the Government should continue to part-subsidise the extra costs involved. The incentives already offered by the Energy Saving Trust under the *Powershift* Programme on the conversation or cost of gas vehicles should therefore continue in its present form.

CONCLUSION

The main factor which could inhibit the development of LPG in the UK is an insufficient demand by users and lack of investment by industry, which in turn will be influenced by fiscal policy. The next budget will be critical in determining how rapidly and extensively the LPG infrastructure will spread throughout the UK.

The Government needs to state its future policy with respect to fuel excise duty over the next 6 years in order that companies can justify the considerable financial investments that they are making. In addition, other organisations who can further influence the infrastructure developments should continue this programme. These include the LPGA, all UK Oil Companies, all UK motor manufacturers, all UK fleet and vehicle leasing companies.

In conclusion, incentives are required to encourage the wider use of LPG for this market. According to the LPGA, these incentives should incorporate:

- a widening of the differential for excise duty for LPG as compared to petrol and diesel; also an assurance that this differential will remain in place for at least 6 years;

- a review of the fuel duty rebate system to give more encouragement for cleaner PSVs;
- developing the concept of 'Low Emission Zones' in urban areas. This is subject to a research programme co-ordinated by the NSCA;
- to allow fleet operators to have a write down allowance in the first year of 100% of the cost of converting a vehicle to gas power;
- to continue with the financial incentives through the Energy Saving Trust for vehicle purchases and conversions while significant differences to capital cost exist;
- encouraging cleaner vehicles by VED incentives.

3. UK Introduction of CNG Vehicles

Contributors: Fred Parker, The Natural Gas Vehicle Association

The Natural Gas Vehicle Association (NGVA) is a trade association representing the interests of its member companies. They include major British, European and American vehicle and engine manufacturers, suppliers of refuelling stations, systems and gas traders and a number of specialist companies in research, development, vehicle and emission testing and conversion.

The NGVA works closely with similar organisations including those in Europe, America and Japan to ensure the transition from conventional fuels to natural gas is accompanied with British, European and International Standards for vehicles, systems and refuelling stations. The Association is also in close contact with a number of UK and EC government departments regarding fiscal, taxation, regulatory and standards issues as well as the future European emission standards under the Auto-Oil 2 Programme.

The Association acts as a facilitator to encourage companies to work together on advanced research and development projects. Considerable investment has been undertaken by the Association in systems and procedures for the accreditation, training and approval of suppliers and conversion companies to ensure the highest standards are set and maintained.

THE FUTURE OF NGVS IN THE UK

The growth of NGVs is world-wide with all motor manufacturers having products or development programmes associated with natural gas. The reason for this is three-fold. Firstly, natural gas is the cleanest of all the fossil based fuels and ideal for reciprocating engines given its high octane rating and low levels of volatile organic compounds. Secondly, the availability of the fuel is world-wide making it a significant alternative to oil based fuels and vastly more reserves than oil. Finally, it has the potential for reducing engine wear giving greater engine life due to the structure of the fuel.

Though the British natural gas vehicle population and related industry as yet remain small, this country has some of the most advanced technology development programmes, a trend which is set to continue. In the UK, as elsewhere, it is well documented that NGVs provide for significant reductions in both regulated and unregulated vehicle emissions (tailpipe and evaporative) and offer substantially reduced noise levels.

The anticipated growth in NGVs is expected to be initially for depot based vehicles, generally operating in the urban environment. The reason for this is the high cost of installing refuelling stations and the need to have a critical mass of vehicles to justify sustainable investment. In many ways the Public Service Vehicles operating in Towns and Cities are an ideal candidate for natural gas. Clean, quiet and customer friendly, they offer a real choice for a change in the mode of transport from cars to public transport.

OVERCOMING THE BARRIERS TO NGVS

It is acknowledged that the cost of NGVs are higher than a conventionally fuelled vehicles, partly due to the high specifications set for the vehicle systems and diseconomies of scale. It is therefore vital that government maintains a commitment to sustaining and widening the tax regime over a number of years to ensure that British industry can play its part not only in the UK but world-wide in the growth of NGVs.

Evaluating the cost and emission benefits from various fuel options needs very careful and detailed research into vehicles, fuel specifications, performance, reliability, running costs usage as well as the required capital investments in order to be able to optimise the maximum benefits. To help in this process, a number of Association specialists are available to give help and advice on the setting up of project management teams. Experience has shown that decisions based on cost alone have not always achieved the desired result.

Since 1993, the NGVA, has played a major part in encouraging government to establish a fiscal regime to help "kick-start" the industry in the UK. This has resulted in progressive changes in the fuel duty taxation year on year; a process which has resulted in the 1999 Budget delivering a substantial duty differential over petrol and diesel. Similar incentives for reducing taxation on natural gas as a road fuel have also been introduced in mainland Europe, USA and many other countries because of the contribution it makes in reducing vehicle related pollution.

The cost barriers associated with the wider take-up of NGVs have progressively diminished as a result of reduced taxation, the introduction of lower vehicle excise duties and the *Powershift* Programme (see Case Study 11). However, there still remains the need to develop a strategic network of public access refuelling stations in the UK. Depot based facilities (local authorities are a good example) can help in this respect by encouraging local partnerships which give third party access to refuelling points. This will be advantageous to the whole community by adding to the local environment the benefits of reduced vehicle pollution.

Given that centrally refuelled Public Service Vehicles are ideally suited to the use of natural gas, there has to be a more rewarding method to encourage operators to switch to natural gas. The current fuel duty rebate scheme still favours the use of diesel making NGVs less attractive from a purely economic point of view.

Looking to the future, NGVs are set to have an important place in global transport. Research into optimised natural gas engines with advance management systems and after treatment demonstrates that the potential for achieving near zero emission vehicles is a technically achievable goal.

4. UK Introduction of Electric Vehicles: The Coventry EV Project

Contributors: Partners associated with the Coventry EV Project
Author: Ben Lane, Strategic Niche Management Project (EU funded)

The Coventry Electric Vehicle Project utilises 14 Peugeot '106 Electric' cars and vans which employ Nickel-Cadmium battery technology. The EVs replace petrol and diesel vehicles and are used by five organisations in the Midlands region of the United Kingdom. Vehicle applications include a local authority car-pool, business use and light duty freight delivery services.

PROJECT OBJECTIVES

The overall aim of the Coventry Project is to *"bring together a wide range of partners interested in promoting the role that the modern electric vehicle can play in improving the environment in the United Kingdom"*. In 1997, the partners believed that the time was right *"to seriously begin the process of introducing zero pollution vehicles into the UK urban environment, in a demonstration project which will attract major attention and awareness of their benefits"*.

According to Peugeot's managing director Richard Parham, the Project tests "whether electric vehicles have a role to play in practical business use the Coventry Project is a ground breaking experiment which will find out if these vehicles can be economically feasible in certain operating conditions. It underlines [Peugeot's] commitment to research new technology and also tests the concept of use in a work situation". Noel Bureau of PSA (Peugeot UK's parent company) sees the Project's main aim as *'sensitising UK fleet operators to the potential benefits of electric vehicles'*.

PROJECT SUMMARY

The Coventry Electric Vehicle Project utilises 14 Peugeot '106 Electric' cars and vans. The EVs replace petrol and diesel vehicles and are used by five organisations in the Midlands region of the United Kingdom. Vehicle applications include use for regular mail-collection service, delivery of light freight to schools and council depots, for catering use and delivery of parts within Coventry (Peugeot), staff commuting use and pool-cars (Council and PowerGen) and demonstration purposes in the local community.

The vehicles utilise Nickel-Cadmium battery technology and DC Leroy Somer motors. They are identical in specifications and performance to the vehicles used within the experiment at La Rochelle in France, except that the vehicles have been converted to

right-hand drive. A full re-charge takes approximately 6 hours which, at the night-time price tariff, costs less than 40p (1996 prices). This gives a vehicle range of around 72 km, a 'fuel' economy of 0.75 MJ/km at a cost of less than 0.7 p/km using night time electricity.

The six partners who are co-operating in the scheme are the Energy Saving Trust, Peugeot Motor Company PLC, Coventry City Council, East Midlands Electricity PLC, Royal Mail Midlands and PowerGen PLC. The Coventry Project was announced in November 1996, the vehicles were officially launched on 12th February 1997 and though the *Project* was initially planned to last for one year, it has been extended and is likely to continue well beyond the end of the 1998.

The Project initially cost £400,000 which has been part-funded by the Energy Saving Trust's *Powershift* programme. This scheme is part of the British Government's commitment to reduce the nation's energy use and greenhouse gas emissions. As one of *Powershift's* pilot schemes, the 14 EVs within the Coventry Project are being leased to the partners for the price of a conventional diesel model.

Peugeot and Coventry City Council had been discussing the idea for a Coventry based EV project since the early 1990s. Peugeot were looking to emulate the French experiment at La Rochelle in 1994. In early 1996, Jonathan Murray of the UK Government's Energy Saving Trust approached Peugeot and Coventry City Council proposing to assist with funding an EV project, knowing of their long standing wish to demonstrate an EV fleet. Subsequently, Coventry Project did indeed become one of the pilot projects within the *Powershift* programme.

PROJECT OPERATION

The Project's primary achievement is to dramatically raise the profile of battery EVs in the United Kingdom. This is shown by the huge media interest during the *Project* and by the enthusiasm of local authorities who are keen to use this technology. Almost without exception, the 106E has had a very positive response, both as a zero-emission vehicle with the potential to reduce gaseous pollution and as a high performance 'real' car which sufficiently satisfies driver's expectations of what a car should be. Local authorities and businesses throughout the UK have watched the Project with great interest; many of them deciding to include battery EVs in future fleets as a direct result of the Coventry demonstration.

Driver responses which have been collected for detailed analysis, together with anecdotal evidence provided by the drivers, has predominantly been in the vehicle's favour. Although initially sceptical about the idea of driving an EV, the prospective drivers within the *Project* were pleasantly surprised with the 106E. According to Mike Horlor of the Royal Mail, "when told they were getting a couple of electric vans our drivers expected to see a milk float, but when they saw a near-normal Peugeot they were delighted".

One environmental impact of the 106E has been a reduction of noise pollution, a problem which is increasing in urban areas and near major roads. As vehicle noise is predominantly due to engine noise at low speeds, this will be drastically reduced by the introduction of EVs. Interestingly, Coventry's blind community have reportedly already expressed their worries to Coventry City Council about the lack of noise from the 106Es and also about the increase of pavement 'furniture' with the introduction of re-charging units around the city.

The main barrier to the implementation of EVs is the vehicle's high capital cost. The support of the *Powershift* programme may go some way to removing the disincentive of increased cost by the part funding of the difference in cost price between EVs and petrol/diesel cars. The scheme can subsidise up to 75% of the additional capital cost of battery EVs as compared to their conventional counterparts. After a period of subsidy, the market may then be in a position to operate without financial assistance through increased volume production with an associated reduction in initial capital unit cost.

Other uncertainties which the Project has addressed are related to energy. To gauge fuel consumption, the Project had planned to monitor the vehicle closely. However, a minor weakness within the *Project* was the monitoring which had not been set up fully from the project's initial stages. Although four vehicles were to have had 'black box' data-logging equipment from the start of the project, these were only fitted 7 months into the project's first year. This turned out not to be such a problem as the Coventry Project will run well beyond the initial year planned, but it might have been interesting for partners to have seen the performance statistics of the project's early stages when the vehicles were still novel to the users.

Other barriers which have been investigated include the need for an extensive slow and fast-charging infrastructure. For the most part, overnight charging has sufficed. However, fast chargers have enabled the full potential of the EVs to be realised through the use of opportunity charging which enables some of the vehicles to complete 130 km a day (almost twice the vehicle's range). Thorough driver training has also proved essential in achieving efficient energy use and maximising the vehicle's range.

The involvement of the Energy Saving Trust was crucial in providing the funds required for an extensive EV demonstration project. It has not only made the Coventry Project possible, it also promises to address some of the economic barriers faced by new vehicle types by making funds available to subsidise of the extra cost of EVs. Furthermore, it provides an organisational link, connecting projects such as Coventry Project with the new Department of Environment, Transport and the Regions (DETR) and the Department of Trade & Industry (DTI), who can encourage the uptake of alternative fuels (such as maintaining differential fuel duties).

As a major fleet operator, Royal Mail is potentially an important purchaser of battery EVs in the UK. However, though the company has been impressed with the vehicles, they have unfortunately not been able to utilise the vehicles fully as their minimum payload requirement is 500 kg; the Peugeot 106Es are only capable of carrying 130 kg. Moreover, the volume capacity of the 106E is smaller than the base specification of 80 cu foot which is the capacity of their widely used small vans. Therefore, for future use, Royal Mail prefer the larger volume-capacity Peugeot Partner electric vans which have a 500 kg payload (at the expense of a smaller operating range of approximately 32 km).

Throughout the project, the importance of highly motivated partners has been crucial. Coventry City Council have been key in attracting vehicles and interest in the Coventry region. They have also developed a great deal of interest through the network of local authorities who wish to reduce the impact of transport on the environment. Partners such as East Midlands Electricity and PowerGen have also widened their experience of battery EVs.

Evidence for the success of the Coventry Project is shown by the fact that many of the partners have decided to purchase EVs to use as part of their fleets in addition to the vehicles used within the Coventry Project. Royal Mail are intending to buy four Partner Vans, PowerGen at least one 106E, and Coventry City Council will purchase eight EVs. Nationally, applications have been made for *Powershift* and Zeus funding for further electric vehicles (mostly Peugeot 106Es and Partner Vans).

By the end of 1996 (before the start of the Coventry Project), Coventry City Council had already applied for Zeus AFV procurement funds under the EU's Thermie programme. Their application was subsequently accepted in 1997 by the project leaders in Stockholm. This will lead to an additional 50 EVs for the Coventry region over and above those that would be used within the Coventry Project. Interestingly, the scope and expectations of the Zeus project in Coventry is now far more ambitious than it would have been had the city not already been part of the Coventry Project. In a sense, and although it was conceived at an earlier stage, Zeus can be seen as a development beyond the Coventry Project for the city of Coventry.

PROJECT EVALUATION

The experiment has been an almost total success in confirming the technological aspects of the 106E and its recharging infrastructure. This is not too surprising as the vehicle had been previously developed over many years by PSA. With the not insignificant modification of having to produce a right-hand-drive version, the technology was already as demonstrated in France. However, it is reassuring that the vehicle has performed well in the UK as elsewhere.

From an outsider's perspective, it is interesting to question not only the project's success in fulfilling its goals, but also the aims themselves. Although the Coventry Project succeeded on its own terms, the Coventry Project cannot be considered a highly ambitious experiment when compared to other EV projects such as Mendrisio in Switzerland. In their defence, it should be noted that Peugeot have been extremely methodical in their staged development of a commercial battery EV. They have finely balanced the need for a high performance vehicle which could attract market share, with the policy of reducing financial risk by converting an existing model and conducting a thorough process of experimentation.

What is certain is that as long as a battery EV's range is small in comparison with conventional vehicles, the identification of specialised niches will be crucial to the successful commercialisation of electric traction. This is because, without severe environmental penalties for conventional vehicles, battery EVs are unlikely to be able to compete with ICE technology on a performance or financial basis. Therefore, applications which maximise the relative benefits of electric vehicles will enhance their attractiveness to potential customers. These niches include use as short-range, urban vehicles and for fleets with predictable duty-cycles; applications which the Coventry Project has demonstrated are ideally suited to electric traction technologies.

Lastly, it should be noted that, without the financial assistance from the Energy Saving Trust, the Coventry Project might never have happened. In return for this Government support, the Coventry Project has acted as a high profile demonstration pilot project within *Powershift*. This initial funding itself has resulted in Coventry's application for Zeus funding being far more ambitious than it might otherwise have been. The *Powershift* and Coventry EV Projects have therefore mutually benefited from each others existence.

However, due to the current price premium of new vehicle types, the market share for battery EVs remains limited by the amount of government and European funding subsidies available. Without these grants, the commercialisation of battery EVs would probably slow to a halt in the UK. It remains to be seen how the free market will respond to vehicles such as the 106E and the Partner Van once subsidies have been removed. Only then will it be possible to say if projects such as the Coventry Electric Vehicle Project have succeeded in promoting the introduction of battery EVs in the United Kingdom.

5. The 'ASTI' Accessible Minibus Project

Contributors: Partners associated with the ASTI Accessible Minibus Project
Author: Dr Stephen Potter, Strategic Niche Management Project (EU funded)

The ASTI project involved development and service introduction in central/inner London (UK) of a fleet of 3 battery electric and 3 CNG-powered minibuses accessible to people with reduced mobility. These replaced diesel minibuses, and were combined with trip-allocation software and vehicle tracking technologies to optimise their use, together with other minibuses, in an upgraded service.

The ultimate aim of the ASTI (**A**ccessible **S**ustainable **T**ransport **I**ntegration) project was to develop an improved and more efficient transport service for people with reduced mobility. Within this, reducing the environmental impact of specialist transport service operations was a key sub-goal and so alternative-fuel technologies were to be explored. The ASTI project was therefore seen as a demonstration project to evaluate both cleaner vehicle/operations technologies and new ways of organising specialist transport for people with reduced mobility.

Consequently, the project sought to establish (a) a network of specialist service operators and (b) a network of partners to develop and introduce the three main technologies involved.

These networks were to develop and introduce into service the alternative-fuelled vehicles as part of a newly organised community transport service ('PlusBus') in order to demonstrate the viability of both to the specialist transport sector.

PROJECT DESCRIPTION

The ASTI project utilises 3 battery-electric and 3 CNG-powered minibuses. These replace diesel vehicles in Camden Community Transport's fleet and are used to provide specialist 'door-to-door' services for people in central and inner London who are largely unable to use conventional public transport.

The battery-electric minibuses are conversions of Iveco-Ford vans and utilise lead-acid batteries, an AC Indramat motor and a Wavedriver controller. Utilising opportunity charging of up to 40 minutes per day, in addition to an overnight charge, these vehicles have a 130km range. The CNG minibuses are conversions of the same van and use a dedicated CNG Iveco engine. They also were designed to achieve a range of 130km/day.

The trip allocation software and satellite positioning technology permit passengers to be allocated to the optimal vehicle for their trip. This integrates the use of the accessible vehicles run by several service providers (health, social services, London Dial-a-Ride and Camden Community Transport).

The project began in 1995, with vehicle introduction in 1996. The project officially ended in early 1998, but the vehicles remain in daily use with Camden Community Transport.

There were nine partners who co-operated in the three inter-related technology projects making up ASTI. These were Camden Community Transport (project leaders), the London Borough of Camden, Wavedriver Ltd., Powergen PLC, London Electricity PLC, the Motor Industry Research Association (MIRA), Stormont Trucks, British Gas PLC and Signal Computing.

The two-year project, involving the funding of the electric and CNG buses and the tracking/trip allocation software, cost £1.85m (2.7m Euro). Of this, £0.45m came from the London Borough of Camden, £0.42 from the CEC LIFE programme, £0.40m from the public and voluntary sector partners, £0.375 from private sector partners and £0.20m from the UK Department of Trade and Industry.

The project originated from discussions by three key people in Camden Community Transport, Camden Borough and the Community Transport sector, who believed that a clean transport technology demonstration project was needed to get specialist transport operators to take environmental issues seriously. Despite a strong social responsibility ethic, the sector had failed to take environmental concerns on board. The availability of CEC funding (successfully obtained after one failed bid) provided the catalyst for ASTI.

PROJECT OPERATION AND IMPACT

The Project's primary achievement has been to raise the profile of alternatively-fuelled vehicles among providers of specialist transport for people with reduced mobility in the United Kingdom. Two major dissemination workshops have been held, together with many private technical visits, coupled with strong specialist and general media interest.

Both types of vehicles have achieved their technical and reliability requirements. For the electric-battery bus this is notable as previous experiments in the UK have usually faced technical problems. The use of an AC drive and Wavedriver control system has been influential in EV development in the UK. Overall, ASTI has shown that an electric-battery minibus is technically and operationally possible for inner-city community transport operations, which had been a matter for doubt before the project. The electric buses in particular have been welcomed by passengers and drivers alike for their quiet and smooth operations, although bus heating was a minor technical problem.

Other specialist transport operators have purchased ASTI-type CNG-powered minibuses and the trip allocation/vehicle tracking software is now commercially available and is a successful product.

BARRIERS AND POLICY ISSUES

CNG minibuses are now nearing commercially viability in the UK, particularly given tax incentives for cleaner fuels. However, for EVs, the high capital cost of vehicles remains a significant barrier. Accessible conversions cost about £100 000, which could be halved if batch production of 12 or more vehicles could be achieved. Overall, EV minibuses have a niche city/town centre market and it seems likely that other alternative fuels could prove cheaper and have a wider application that battery-electric vehicles.

The ASTI project has established that an AC drive vehicle can exploit opportunity charging using the Wavedriver technology to extend range. Driver training also proved necessary to maintain the electric bus's range.

Despite these important advances, although ASTI has established the technically viability of a battery-electric minibus for inner city operations, the commercial case for battery-electric minibuses remains weak, particularly compared to other cleaner fuels.

FINDINGS OF THE PROJECT

The availability of CEC funding under the LIFE programme was key to pulling the project together. This provided the necessary funds for a project in a sector that had, until ASTI, shown no practical interest in alternative fuels or the issue of emissions from diesel vehicle operations.

ASTI was a complicated project which required a large number of partners and suppliers to develop and introduce the three inter-related technologies and a further operators' network for the service development itself. This complex product and service design management task should not be underestimated and the lack of serious management problems is a notable achievement of the ASTI project.

The choice of partners resulted in a powerful combination of organisations for whom ASTI was important to developing their core activities. To none of them was ASTI a peripheral 'experimental', low priority job. All the private sector partners believed that ASTI's success would pay them commercial dividends. For the operators and public sector partners, ASTI's objectives related closely to their core needs and development issues. The method used to select partners specifically sought to test their motivations and resulted in a network of highly-motivated partners and suppliers.

The fact that the lead partner, Camden Community Transport, is a 'Social Economy' co-operative organisation appears to have played a significant part in this management success. Community transport operators in Britain have a culture of working in partnership with their suppliers, with public authorities and users (who elect their management committees). This suggests that for complex demonstration projects with multiple stakeholders, the use of organisations familiar with complexity and a co-operative, partnership approach would be appropriate.

FUTURE PLANS FOR THE PROJECT

The ASTI project established a new 'PlusBus' accessible service in inner London involving the alternative-fuelled ASTI buses and conventional diesel vehicles. Having been established by the project, this service is now permanent and acts as an ongoing demonstration of advanced technologies for specialist transport operations.

PROJECT EVALUATION

In confirming the technological aspects of CNG and battery-electric accessible minibuses and the trip allocation/tracking software, the ASTI project is a total success. The co-operative partnership management of the project has been notable, with its careful choice of networks of highly-motivated organisations.

Although the project established the viability of battery-electric minibuses in an inner-city context, it has also shown that, even compared to other alternative fuels (particularly CNG), the identification of specialised niches will be crucial to the successful commercialisation of electric traction. Niche applications include use as short-range, urban fleets with predictable duty-cycles. However, even with fiscal penalties for conventional vehicles and/or financial incentives for cleaner fuels, battery EVs will find it difficult to compete with CNG or other alternative fuel technologies on a performance or financial basis. This is so even for the applications in which EVs perform best.

The environmental impact of the trip allocation and vehicle tracking software should not be underestimated. This has produced a greening through optimal resource management. This has improved vehicle occupancy and cut empty and low-occupancy running while providing a better, more intensive service for users. This reinforces the need for clean transport technology demonstration projects to address the transport system rather than just the vehicles within it. ASTI is the rare example of a clean transport technology demonstration project that explored both two cleaner vehicle technologies and also technologies that enabled environmental improvement to be achieved through the redesign of the transport system itself.

6. Local Authority Perspective: Westminster City Council

Contributor: Leith Penny, Westminster City Council

The City Council has a policy to reduce emissions in its own fleet (a small number of just over 100 vehicles) and to encourage its own contractors and other fleet operators and individuals to do likewise. To achieve these aims the Council has:

- adopted a replacement strategy for its own fleet which aims to reduce particulate emissions by 95% by 2000;
- included relevant clauses in tender documentation for contractors;

- developed a Green Pennant award scheme for owners of low emissions vehicles;
- held large-scale seminars on AFVs for fleet managers operating in central London;
- worked with fuel suppliers to develop a refuelling infrastructure in central London.

The City Council's experience with AFVs began in the early 1990s working with London Transport buses and Eminox on the production of catalysts for particulate traps and CRTs for diesel engines. This was made possible by the availability of Ultra Low Sulphur Diesel (ULSD) which was supplied by Greenergy; at the time a relatively unknown fuel. These bus trials convinced the City Council of the benefits of particulate traps and prepared the way for the first in-service AFVs.

In 1995, when the City Council were to let a large contract for cleaning and refuse vehicles, all tendees were asked to offer contract options involving the use of CRTs and ultra low sulphur diesel. The winning contractor (Onyx UK Ltd.) set up a programme to retrofit all of their vehicles with catalysts. Westminster City Council set up a contract with Greenergy to supply a fuel pump for City Diesel at a council depot. Monitoring by Millbrook in 1996 (funded by Westminster City Council) showed that, for a typical refuse collection cycle, City Diesel and CRT technology reduced particulate emissions by 88% on a hot start and 51% on a cold start.

The City Council has developed a strategy for its own in-house vehicles, switching to City Diesel and exhaust after treatments for its fleets and introducing gaseous fuels and electric vehicles when cost-effective as they became available. At present, the City Council's AFV fleet includes 22 minibuses fitted with CRTs and 13 dual-fuel cars, vans and minibuses (LPG/petrol and CNG/petrol). Other AFVs used within the authorities region or launched by Westminster City Council include a CNG London Taxi, the Zevco fuel cell London Taxi and a small electric truck. A hydrogen fuel cell vehicle for use in parks is to be purchased shortly. Over the past 4/5 years, the City Council has had a number of small electric vans on trial, for mail delivery and transporting street enforcement staff, though none has so far met the Council's operational requirements.

An initiative started by the Council is the *Green Pennant Scheme*, an award which is accredited to operators who introduce clean vehicles within the Westminster region. This provides a operators with a means of publicising their decision to convert to 'greener' fuels and raises the profile of AFVs and the associated environmental issues. The clean fuelled vehicles listed above have all been awarded a Green Pennant by the Council.

MOTIVATIONS TO INTRODUCE AFVS IN WESTMINSTER

The Council's motivation for the introduction of AFVs is to improve air quality. The key pollutants the City Council is concerned to reduce are particulates and NO_x. The Council's Review and Assessment of Air Quality shows that the standards in the National Air Quality Strategy for these two pollutants are exceeded more or less across the whole city. The motivation to develop and implement this policy came from officers and Members in response to the findings if air pollution monitoring which the City Council has conducted extensively over the past two decades, and a number of studies coming from the USA in the early 90s about the health effects of particulates.

Choices of alternative fuels are made relative to cost, and whether vehicles can do the job required. This is also the Council's policy in recommending their use to others. In general, the Council is prepared to make additional investments in cleaner vehicles, but only where that investment can be shown to represent 'good value' in terms of the reduction in emissions achieved per pound of expenditure. There is always a requirement for officers to show value for money, and this applies to emissions reduction as much as to the vehicles themselves. On occasion, exceptions are made where it is felt that the City Council can, through a 'strategic' investment, materially assist in the development, proving or spread of a significant new fuel or technology (e.g. the purchase of a hydrogen fuel cell vehicle).

One of the objectives of the Council's approach is to help stimulate demand and to reduce production costs, so that the price differential between AFVs and conventional vehicles is reduced. Ultimately the aim is to reduce the cost of AFVs and to demonstrate their practicality, rather than to promote their proliferation on the basis of grants and tax breaks.

BARRIERS TO THE INTRODUCTION OF AFVS IN WESTMINSTER

The main economic barrier to introducing AFVs is the cost of a purpose built vehicle. Ignoring the issue of availability of suitable vehicles, those which are available are still significantly more expensive than the diesel or petrol standard. The Council's strategy to date has been to take the most cost beneficial route which will yield quick and significant results. Hence the Council have converted to ULSD with catalysts where possible and have had petrol vehicles converted to LPG.

Costs of the Council's fleet strategy in regard to alternatively fuelled vehicles are:

- Costs of tests on Cleansing fleet £9,000
- Cost of equipping cleansing/waste fleets with CRTs £290,000
- Consultancy to advise on strategy £13,000
- Capital costs for fitting 12 LPG kits £12,000
- Purchase of the fuel cell vehicle (pending) £33,000

Costs involved in the promotion of AFVs to others are:

- Green Pennant Scheme £8,200
- Seminars (costs less income from sponsorship/delegate fees) £4,000

Initially the use of ULSD incurred a premium of 3p/litre, representing an annual additional cost of £60,000 to the cleansing contract alone. This has subsequently reduced to zero through the introduction of a duty differential in favour of ULSD. Operating costs are reduced through the use of LPG which is almost half the price of petrol.

PROMOTIONAL MEASURES USED TO ASSIST THE INTRODUCTION OF AFVS

The policy for promoting AFVs has been developed by the City Council's Environment Group. The Council's own fleet strategy is approved by the Council's Chief Officer Board and is co-ordinated by the Transport Manager in liaison with individual service managers.

In implementing the policy to the private sector, the response has been almost entirely positive. The majority of fleets operators with whom the Council has dealt are keen to take action to improve emissions from their fleets. The key issues for them are cost, availability, operational specification and reliability. Fleet operators are grateful for easily accessible information to enable them to make intelligent choices. This has been the strategy behind the seminars held by Westminster City Council, which are now an annual event.

Importantly, the experience which Westminster City Council has gained has shown what can be achieved by working with private sector partners who have the technology and expertise who were looking for a proving ground. The Council's interest in catalyst technology has meant that Eminox have worked continually to improve the design and hence performance of the catalysts and produce new designs for vehicles for which traps had been previously unavailable.

Since 1997, the Council have included a clause in all tender documentation setting out the Council's clean fuel strategy and asking contractors to specify what type of fuel they will be using in their vehicles. This has already led to two contractors opting to use LPG and several using ULSD. In one case, the Council has offered the use of the LPG refuelling site located on Council land.

The implementation of Local Air Quality Management will encourage local authorities to work together, if they not already doing so, on ways to improve air quality. Westminster already networks considerably with other central London boroughs. The issue also requires the input of other experts and of the business sector. Westminster has invited ALG to chair an 'expert panel' of the central London boroughs. Representatives from the boroughs will include environmentalists, transport and planning policy officers. Other representation will include health authorities, research organisations, London Transport and representatives from business.

The National Air Quality Strategy has been of positive assistance in Westminster in as much as it:

- sets the Council's policies and initiatives in a statutory framework and hence gives some 'teeth' to the measures the Council has asked fleet operators to take;
- provides a focus for local authorities to work together;
- helps identify necessary action by the setting of specific standards for individual pollutants and time-scales in which to act;

Lower duty on gas fuel and reductions in VED has also been of assistance to the Council with ULSD and vans, LGVs and HGVs fitted with catalysts.

INFRASTRUCTURE FOR CLEAN FUELS

In order to support the emerging AFV fleet, Westminster City Council has worked with the suppliers of alternative fuels in an effort to get a refuelling infrastructure in central London. Initiatives include:

- the opening of the first LPG site at a shell garage in Victoria in 1998 – other Shell sites in Westminster are planned;
- the installation of an LPG refuelling site on Council premises in 1998 in association with Calor Gas – the plans for Calor Gas to make provision for a public access LPG refuelling point in Westminster (a suitable site has yet to be found);
- the installation of a suitably designed electric charging station to be located on the street and in Council car parks (in association with PowerGen);
- the negotiating for the supply of ULSD, 'City' petrol and other alternative fuels at car parking sites owned by the Council.

Development of an alternative fuels infrastructure accessible to the general public is constrained, and likely to be more constrained in future by the loss of fuel forecourt sites to alternative uses and the development of retail uses on existing forecourts; both of which limit the opportunities for providing new fuels (especially LPG) alongside conventional petrol and diesel. In the current view of Westminster's Unitary Development Plan, the Council are including a policy to safeguard garage forecourts which may be suitable for the provision of alternative fuels. There is a concern that products other than cleaner fuels may be competing in the future for premium forecourt space.

ROLE OF LOCAL AUTHORITIES IN PROMOTING AFVS

The lessons which can be drawn from Westminster City Council's experience of managing the introduction of AFVs suggest the following additional recommendations for all UK local authorities:

Planning Policy – Local planning authorities should consider the availability of facilities for alternative fuels within their areas, and the inclusion of appropriate policies within their Unitary Development Plans to protect sites suitable for the development of an alternative fuels infrastructure. Consideration should also be given to opportunities to develop new refuelling infrastructure (e.g. fast recharge points in car parks). Indeed, local authorities could include the planning requirement that provision be made for alternative and/or cleaner fuels within new filling station forecourt developments.

Local Authority Purchasing – In preparing specifications and tender documentation for the provision of vehicles (whether by lease, purchase, or in association with other services), local authorities should include environment performance criteria within the specifications, or alternatively, include environmental performance among the criteria to be applied in evaluating tenders.

Partnerships for developing a fuel infrastructure – Local authorities are often significant landowners within their areas. Where suitable opportunities exists (e.g. on expiry of a lease on a forecourt or depot site), they should consider the desirability of entering into partnership with energy suppliers or other willing parties to develop them as multi-fuel 'alternative fuel centres' (offering, for example, ultra-low sulphur fuels, gas and fast charge electricity on the same site).

Green Transport Incentives – Local authorities should consider the introduction of incentives to the adoption of alternative fuels. Examples include the provision of free parking for AFVs (currently offered to EVs in Westminster) and/or the establishment of accreditation schemes (c.f. Westminster's 'Green Pennant') which provide operators with a means of publicising their decision to convert to 'greener' fuels.

CONCLUSION

Westminster City Council seeks as a matter of policy to assist in the proving and development of promising new emission reduction technologies. It hopes to repeat the contribution it was able to make in relation to ULSD and CRTs in other key 'City', targeting in particular those that offer cost-effective solutions for the existing vehicle fleet (e.g. City Petrol) and those that offer the greatest potential long-term benefit (especially hydrogen fuel cells).

The Council considers it a duty to lead the development of local partnerships and strategies to improve air quality. Indeed, in 2005, Westminster (as will all other local authorities) will have a statutory duty to ensure that a range of air-borne pollutants are maintained within legally prescribed limits (UK National Air Quality Standards). They need guidance on how cleaner fuels could contribute to local air quality strategies on measures likely to encourage the use of vehicles using cleaner fuels in air quality management areas.

Such measures might include:

- spear-heading local information campaigns and negotiating voluntary agreements with local fuel retailers, public transport and fleet operators;
- seek to attain powers to set environmental performance criteria for vehicles operating in air quality management areas or Low Emission Zones;
- co-ordinate the promotion of cleaner fuel provision with the areas of planning, local authority purchasing, forming partnerships within the business community and implementing local transport policy.

7. Local Authority Perspective: Merton CNG Vehicle Fleet

Contributors: Partners associated with the Merton CNG Vehicle Fleet, Ben Lane, Strategic Niche Management Project (EU funded)

Over 25 CNG vehicles have been introduced into the London Borough of Merton, UK. A wide variety of vehicles are being used and the fleet includes dedicated minibuses, bi-fuelled car-derived vans and dedicated refuse collectors. These vehicles comprise part of Merton's vehicle fleet which provides services for the Borough.

THE OBJECTIVES

The objective of the introduction of the CNG vehicle fleet is to improve local, regional and national air-quality and to adhere to the environmental policy of the London Borough of Merton. The original long-term objective was to replace all vehicles with CNG.

Merton is making considerable progress in implementing Agenda 21 and more recently the local Air Quality Strategy. Merton Transport Services part in this has been to investigate ways in which locally, the authority could reduce the impact on the environment caused by emissions from a large diverse fleet operating in an already over congested urban Borough.

PROJECT SUMMARY

Since 1997, over 25 CNG vehicles have been introduced into the fleet operated by the London Borough of Merton, UK. A wide variety of vehicles are being used and include:

- 19 CNG dedicated minibuses and coaches – e.g. Iveco Daily Series
- 12 CNG bi-fuelled cars and car-derived vans – e.g. Ford Courier vans
- 6 CNG dedicated Refuse Collectors – e.g. Iveco EuroTech Series (4/6x2)

These vehicles are used by Merton to provide services for the Borough. Uses include a wide range of collective passenger, refuse collection and meal delivery applications within the sub-urban areas of Merton.

The main project partners are Merton Transport Services, British Gas, Ford/Iveco Truck, Energy Saving Trust and the Zeus Project (funded by the European Commission through the Thermie programme).

Merton Transport Services is part of the Environmental Services Department of Merton Council. It is responsible for the management and procurement of fleet vehicles and plant. The current fleet consists of 200 plus vehicles ranging from car derived vans to 26 tonne refuse collection freighters.

British Gas is supporting the project by installing the refuelling station. The private company are keen to be involved with UK projects which are demonstrating the advantages of alternative fuels and are involved with several other UK CNG vehicle projects (e.g. Travel West Midlands).

In return for the refuelling infrastructure, Merton have agreed a contract to purchase gas from British Gas for a minimum period (probably around 10 years).

Ford/Iveco are keen to capture the market for CNG vehicles. If proven, their CNG vehicles could be increasingly used throughout the UK. The company has much previous experience with CNG vehicle manufacture and operation and are involved with several other demonstration UK projects.

The Energy Saving Trust is subsidising vehicle costs through the *Powershift* programme which aims to kick start the UK AFV market by using government money to fund up to 75% of the increased cost of alternative fuelled vehicles. The programme has no preferred fuel regime and includes CNG, LPG and electric vehicles within its portfolio.

The Zeus Project provides a link with many other AFV projects throughout the UK and Europe. These include Stockholm, Athens, Helsinki, Copenhagen, Palermo, Luxembourg, London Boroughs of Sutton, Camden, Southwark, and Coventry City. Thermie is also contributing to the project costs.

At the project's inception, three main areas were identified within the Transport Operations where it was believed that the use of the alternative fuel sources would have an immediate and sustainable effect. These were for *refuse collectors, accessible passenger mini-buses/coaches and car-derived vans for meals on wheels service*.

Numerous alternative fuels were considered and evaluated according to the following criteria: same fuel source for all vehicles, cleaner than current fuels, fuel availability, size of refuelling facilities, vehicle and fuel cost and the willingness of vehicle manufacturers and fuel suppliers to sponsor the project. This led to an evaluation of the following alternative fuels: *LPG, CNG, bio-diesel, hybrid diesel-electric, low sulphur diesel and battery electric*.

Following the evaluation, it was decided that CNG was the only readily available fuel that met Merton's requirements. The major conditions were for reduced emissions, fuel availability, size of refuelling facility which needed to fit into a very small depot. It was decided at this point (in 1995) that Merton would carry out whole life evaluations on a vehicle fleet basis.

PROJECT OPERATION

Maintenance operating costs have been reduced for CNG operation (as compared to diesel) by approximately £47,000 per annum. This was important as the move to CNG had to be cost neutral at the very least. However, more recently, maintenance problems have led to a re-think regarding future expansion of the CNG fleet.

In retrospect, it is considered that the right organisational structure was used for the project. This included the involvement of Iveco Trucks, British Gas and in the Zeus project (working in conjunction with Coventry and other London Boroughs).

The Ford Courier vans (meals on wheels) have operated without fault, though the drivers dislike the complication of having to go out of their way to fill up at a natural gas station. The buses lack power and the drivers have complained about the increased cab temperature due to heat from the engine. Nor do they like the quietness of the engines or the inconvenience of only having one refuelling station. The refuse truck is favoured over the diesel as it is easy to drive, quieter and they avoid getting choked by diesel fumes when working at the rear of the vehicles.

One refuse vehicle went out of service after it caught fire in April 1998. The fire was probably caused by hydraulic oil leaking onto the exhaust pipe and it was confirmed that the gas system played no part in the fire. The forensic report stated that the gas cylinders vented the gas to the atmosphere when the critical temperature was reached. Gas is released in these circumstances so fast that the oxygen in the air is not able to aid combustion.

Passenger awareness of CNG vehicles was improved overall and was shown by anecdotal evidence; when a diesel bus replaced a CNG one, passengers noticed the higher noise and pollution levels, which, in general were lowered as compared to conventional fuel operation.

BARRIERS AND POLICY ISSUES

High vehicle costs currently present the main barrier to the introduction of CNG vehicles into the Merton fleet. The extra costs per vehicle are approximately £20,000 per truck, £3,000 per coach/bus and around £2,600 per car derived van. Though *Powershift* and Zeus subsidies were available to fund between 50% and 75% of the extra costs, this economic barrier remains.

There was an administration problem with the Zeus Project. Only £18,000 out of £98,000 of promised funding was available at the start of the project. A quicker response time would have aided the implementation of the project.

For mini-buses, low vehicle range and high vehicle weight are major disadvantages of CNG. Weight of storage tanks also poses a problem for refuse vehicles. Iveco have since increased weight of the refuse vehicle chassis.

Certain existing legislation initially hindered the introduction of CNG vehicles. Construction and Use regulations acted a barrier as a Special Vehicle Order was required to operate the CNG vehicles. Also, for gas equipment, all services needed to be CORGI approved. However, at present, no regulations are hindering the CNG fleet operations.

Initially, general awareness of CNG vehicle was low. This was improved by a public display at the civic centre. In addition, the maintenance crews had to be all retrained to use gas fuel supply system and computerised diagnostics.

FINDINGS OF THE PROJECT

The project met and surpassed all the initial objectives. These included compliance with Agenda 21 targets and the Clean Air Strategy. The project has shown that CNG vehicle technology is reliable and environmentally beneficial and that operating costs are reduced, although maintenance problems have proved significant. The remaining issue which continues to require outside intervention is the need for Government assistance with capital costs.

The CNG fleet experience has revealed that there exists an inaccurate perception among drivers regarding CNG. Therefore, more education of users is needed concerning AFVs. A change in driving attitudes was required as drivers tended to over-rev the engine as it was quieter. This came to light early on in the project as fuel use was much higher than expected. However, this was solved through driver training.

PROJECT UPDATE

As of January 2000, the CNG fleet consisted of 19 buses, 12 cars/vans and 6 refuse vehicles. The long-term objective had been to replace all vehicles with CNG. This was to be achieved in stages; by 2005 all refuse vehicles were to be CNG and by 2010 80% of the fleet would be CNG (170 vehicles). The infrastructure was also to be upgraded by installing a larger compressor and a medium pressure main with two more fuelling points are planned for London over the next 3–4 years. However, because of maintenance problems, Merton are reconsidering non-gaseous alternatives (such as ULSD used in conjunction with after-treatment systems) for future vehicles in their fleet.

PROJECT EVALUATION

The CNG fleet introduced in Merton has succeeded in reducing vehicle emissions and operating costs, though has highlighted some problems with maintenance. To offset some of the increased vehicle purchase costs, the *Powershift* programme has provided invaluable capital subsidies.

The experience of the Merton Transport Services has led to the following conclusions regarding the demonstration, assessment and implementation of AFV fleets:

- Choose a fuel which best meets the demands of the transport requirements.
- Stick to one fuel for fleet use. This will make project easier to implement and assess.
- Aim to convert a significant part of the fleet rather than only introduce AFVs in ones and twos. Merton aimed from the start to go for at least 50% conversion to CNG for its passenger, refuse and meal-delivery fleet.
- Choose the manufacturer/model wisely to meet transport needs. The Iveco was chosen on Merton as it was designed as an urban vehicle.

One observation is that the success of the project was helped by the fact that it was led by a transport services organisation and not an environmental team as is more often the case. However, the project team did liase with environmental departments. Through the project, the Borough have become aware of the need for reliable vehicle data from all parts of Europe (emissions, fuel costs, fuel efficiency and maintenance costs) and the need to ensure transferability of emission data, financial analyses and operational experience.

To further assist the up-take of CNG vehicles, Merton recommend that central and local Government should:

- implement financial incentives by reducing fuel duty for CNG to EU minimum and the road fund licence for CNG;
- consider financial assistance for operating costs for some alternative fuels (in addition to capital subsidies);
- make provisions within tendering procedure to ensure environmentally friendly vehicles are used where possible;
- implement Low Emission Zones and implement integrated transport policies and reduce city centre parking provision;
- assist with the standardisation of legislation and fuel quality across Europe.

8. Local Authority Perspective: Cheshire County Council

Contributors: David Lewry, Policy and Projects Manager, Cheshire County Council, Ben Lane, Utopia Project (EU funded)

As part of a larger UK programme of LPG vehicle introduction in the public transport sector, dedicated LPG buses have been introduced in Chester (on the Park and Ride network). Buses provide services to fee paying passengers and have been operated alongside their conventional diesel counterparts.

As of the end of 1999, several LPG buses are in operation. These are the result of a 2 year demonstration of LPG buses in the region; due to end in March 2000. The next sections describe the initial demonstration project and how the project has resulted in the emergence of a small LPG fleet in the Chester area.

PROJECT SUMMARY

In March 1998, an LPG bus entered into service on the Chester Zoo Park & Ride route. This was as part of a larger UK programme of LPG vehicles.

The vehicles used is a SB 220 GG LPG bus (manufactured by DAF Bus International) fitted with an 8.65 litre dedicated LP gas engine. The maximum engine power is 170 kW and the buses are capable of up to 315 mile (500 km) range using a 600 litre capacity LPG tank. The buses can carry 76 passengers.

Transponders are installed which, when in operation, provide real-time information and traffic signal priority. This is part of a larger Urban Traffic Control system designed for all buses in the city.

The vehicle provides routine services for 6 days per week, covering the 3.2 km trip distance 72 times a day. As the vehicle is operated alongside Scania L113 Axcess Ultralow buses fuelled by Ultra Low Sulphur Diesel, this enables an accurate comparison of fuel economy between the two fuels.

All vehicles (LPG and diesel) are refuelled on a daily basis in the early evening (after washing), so there is no extra inconvenience to the drivers with respect to time spent refuelling the LPG bus. The LPG bus requires a refill of approx. 570 litres LPG fuel each day (600 litre tank capacity). It takes no longer to refill the LPG bus than it does for conventional diesel bus.

PROJECT'S OBJECTIVES

Initially, the LPG bus was introduced to demonstrate the viability of LPG buses in Chester (located in Cheshire). This was designed to:

- increase the profile of cleaner fuels in the public eye and operators' portfolio;
- set up a realistic back-to-back, in-service evaluation with comparable diesel buses;
- lay the foundations for more clean buses in the future.

Chester City and Cheshire County Councils are independently keen to promote clean vehicles and are funding the project as part of the Capital Challenge Programme which includes projects to improve the City's public transport network.

ORGANISATIONAL STRUCTURE AND SUPPORT MECHANISMS

In 1996, Shell Gas and the Energy Saving Trust discussed the possibility of a series of UK based LPG vehicle trials. Liaison with bus operators and local authorities interested in the potential of alternative fuels and with the bus supplier Arriva led to four LPG bus projects in the UK.

These LPG bus projects included the demonstration LPG bus operating on a Park & Ride route in Chester (the city had been interested in demonstrating cleaner vehicles for some time). The other projects were short-term trials in north London (3 months), in Bannock, Scotland and in Northampton. Following these trials, the LPG buses no longer used are now available for resale from Arriva.

The partners of the Chester project are Cheshire County Council, Chester City Council, Crosville (First Group), Shell Gas, Energy Saving Trust (EST), and Arriva Bus & Coach. The project cost £175,000 which has come from Cheshire County and Chester City Councils (£65,000), Crosville (First Group) (£100,000), Shell Gas (£10,000) and the EST.

Arriva Bus & Coach are a subsidiary of Arriva PLC (formerly known as Hughes DAF). The vehicle constructed by Arriva use a purpose built DAF engine developed by DAF following encouragement from the Dutch Government. Arriva Bus & Coach hope to increase sales of their LPG (and other clean fuel) buses. First Crosville are part of First Group, a national transport company who also have also extensive experience of trailing clean fuels (such as a CNG bus in Bristol).

The programme in Chester initially introduced a single demonstration vehicle. The County Council leased a bus for a period of 2 years from Arriva Bus & Coach, and provided it to First Crosville under an operating agreement. In addition, a permanent LPG fuelling installation was provided by Shell Gas, in return for a fuel supply contract with First Crosville. The bus was launched on 20 March 1998 as the first dedicated LPG bus in public service in the country.

Shell Gas installed the LPG refuelling facilities. In return, First Crosville are contracted to purchase LPG fuel for an agreed period. Shell Gas, the world's largest producer and supplier of LP Gas, is expanding its network of LPG refilling stations throughout the UK. These are at centralised depots and at conventional garage forecourts for public use.

PROJECT DESIGN

Before the LPG demonstration has even begun, there had been a very thorough prior assessment of the technological alternatives to diesel technology. This involved the preparation of a 40 page report entitled "Alternative Fuels for Buses" written by David Lewry of Cheshire County Council.

The report aimed to provide "an introduction to each of the available alternatives", presented "comparisons of emissions….fuel, operating and infrastructure costs" and reported on "the availability and established uses of alternatively-fuelled vehicles, and reviews the current status of trials".

Hence, the project showed a high degree of planning; with the inclusion of an evaluation strategy as part of its goals. The objectives of the demonstration included the setting up of a realistic evaluation against diesel equivalents. Social aspects of the project were also investigated. This included a questionnaire which was used to assess the response of passengers to LPG.

Of high importance in the project's design was the inclusion of an exit strategy as part of the original strategy. One of the original objectives was to "generate the conditions which would facilitate the adoption of further clean buses in future".

PROJECT OPERATION

To date, the Chester bus has covered 45,000 miles/year and used 57,000 litres of fuel each year. The number of passenger carried as of February 1999 exceeds 50,000.

Monitoring in Chester has shown that bus emissions "have set a new record for production buses (other than electric-powered ones)". Compared with ordinary and cleaner diesel operation, the LPG bus recorded significant reductions in CO, NO_x, HCs and particulates and a slight reduction in CO_2 emissions on a per kilometre basis.

In Chester, the bus drivers commented on the driving experience as compared to the LPG bus with the Scania L113 Axcess Ultralow diesel. The steering is reported to be slightly heavier and the acceleration slightly reduced.

Passenger reaction has been assessed by use of a questionnaire study involving 4000 Park & Ride users which has been undertaken by Chester City Council. Anecdotal evidence suggests that many users are aware of the 'gas bus' and its environmental advantages. The favourable comments have related to the low noise level and the visibly clean exhaust.

BARRIERS AND POLICY ISSUES

Though the Arriva LPG buses have been a great success and have achieved the objectives set by the projects, one key barrier remains. Arriva Bus & Coach, the UK importer for the DAF bus, market the LPG bus at an additional cost of £25,000 per vehicle as compared to the diesel equivalent (£110,000). This extra cost would be greatly reduced if large production runs were possible in the manufacture of LPG buses. However, at current volumes, the extra cost remains a significant issue.

There has been some uncertainty concerning the residual value of a LPG bus, the importance of this factor depending on the position of the partner involved. For example, a lessor's uncertainty of the resale cost will be passed on to the lessee. Having said that, at least three used LPG buses (previously used in short-term trials) are available for purchase from Arriva at the same price as a second-hand diesel. (In the near future, these may be bought by private operators for use in the Chester area.)

FINDINGS OF THE PROJECT

A key element of the project design which made the project in Chester a success was the back-to-back comparison of LPG and diesel buses operating on the same route. This has provided extended operating experience and confirmation of the potential similarity of running costs. Also the project has demonstrated to all interested parties the viability of LPG buses used in real-world conditions.

Other factors which were key to the project's success included funding from *Powershift* programme (administered by the Energy Saving Trust), the potential emission reductions at comparable cost of LPG as compared to Ultra Low Sulphur Diesel and the close partnership with fuel suppliers, in this case Shell Gas.

On the organisational side, the close co-operation of all project partners proved very important for the smooth running of the project. However, there was a minor problem due to a timed required to grant a subsidy from *Powershift*. This made the finances at the start of the project difficult to manage. However, the speed of the funding process is now much improved.

While the bus in Chester was generally well received, there have been a few minor technical problems. The fuel gauges were not quite accurate in the Chester bus. This was due to the fact that the air temperature affects fuel capacity (in this case by around 10%). Also, there was a minor transmission software fault which took the bus out of service for a while and a fuel pump failure. Another bus, in operation with Calor Gas, required unforeseen servicing of the engine management system. However, all these technical problems have since been solved.

FUTURE PLANS FOR THE PROJECT

The project in Chester has led to the following positive outcomes:

- The Chester LPG bus project run on a commercial basis is considered a success in reaching the project's aims. So much so, that another 4 buses were introduced to the region in 1999; delivered to Arriva Cymru (Wales). A separate filling station has been installed by Calor Gas.

- As the demonstration was a success, the County and City Councils invited parallel diesel and gas tenders for Chester's 4th and latest park & ride scheme. The Councils propose to invite parallel tenders as a matter of course.

- A 10% premium for gas buses over the 5-year contract period (totalling £100,000) has been funded from the Capital Challenge Programme, Cheshire County Council and revenue from the Park & Ride scheme.

- Two out of three major bus operators in Chester now have LPG buses and refuelling facilities.

- Shell has extended the scope of their leasing agreements so that vehicles can be leased just through the cost of the fuel.

PROJECT EVALUATION

The project has been a great success in a number of regards. First, time and resources was spent on a thorough planning process which identified which technology would be most suitable for the transport application in question. Second, a demonstration project was adequately financed which demonstrated to all concerned the advantages and viability of the new technology. Third, an evaluation strategy was an integral part of the demonstration phase. Fourth, there was a successful transition from the demonstration to the 'market' phase.

The project has successfully demonstrated that LPG is a fuel suited for collective road transport applications. However, it has clearly shown that the main barrier to LPG buses is the increased vehicle cost. At present, this issue is being partly addressed by the UK's *Powershift* programme which subsidises the extra cost of cleaner fuelled vehicles by up to 75% as compared to conventional models. Though the project partners believe that capital costs will decrease by up to 20% in the future, while cost differentials exist, it is essential this type of support continues for LPG and other cleaner vehicles.

9. Public Transport Operator Perspective: Travel West Midlands

Contributors: Partners associated with the Travel West Midlands CNG Fleet, Ben Lane, Strategic Niche Management Project (EU funded)

14 CNG buses were introduced in the Midlands (UK), completely converting a bus route to CNG operation. The buses used are Volvo GH10A 245s which utilise dedicated Volvo B10L lean-burn CNG engines. The fleet is used for commercial service and link two adjacent urban areas. The service operates for seven days per week with fee-paying passengers.

THE OBJECTIVES

Travel West Midlands (TWM) and their parent company National Express Group are keen to bring cleaner buses into operation in Birmingham and extensive research has identified natural gas as the most realistic option. Travel West Midlands introduced the project to compare CNG bus with diesel operation. The company wanted to experiment with an alternative fuel, improve local air quality, improve their public image and assess the operating costs of CNG buses.

Other objectives include the ability to make a direct comparison of CNG with diesel vehicles, to encouragement of additional clean vehicle projects in the UK, detailing information for promulgation to other bus companies and to expand the CNG market through the provision of a new refuelling stations.

PROJECT SUMMARIES

In July 1997, 14 CNG buses were introduced on a route in the Midlands, completely converting bus route 529 to CNG operation. This route requires 14 buses, 13 for service and 1 for back up. The buses used are Volvo GH10A 245s which utilise dedicated Volvo B10L lean-burn CNG engines.

The fleet is used for commercial service and link two adjacent urban areas. Route 529 provides connections with the railway network at Walsall and Wolverhampton rail stations and the National Express Coach network at Wolverhampton Bus Station. The service operates for seven days per week with real fee-paying passengers.

ORGANISATIONAL STRUCTURE AND SUPPORT MECHANISMS

The four main project partners are Travel West Midlands, British Gas, Volvo Bus Ltd. and the Energy Saving Trust.

In addition to the CNG trial, TWM have had some limited experience with LPG. This fuel is often considered as the main competitor to CNG. However, the company has yet to come to any conclusion about which is best alternative bus fuel.

British Gas, who are a major energy/fuel supplier and distributor in the UK have much experience with other CNG projects. These include projects at Merton (London), Sutton (London) and Bournemouth Borough Council. In the Midlands Project they provided and maintained the gas refuelling stations. In exchange for providing refuelling infrastructure for the project, BG had a contract to supply natural gas to Travel West Midlands

Volvo has had much previous experience in the manufacture of dedicated CNG engines and vehicles. In addition to the CNG buses in the Midland's project, six are with FirstBus in Northampton and one is in operation in Dublin. Also, Volvo overall has around 400 CNG buses in service in Europe, mostly in Sweden but with small fleets in France, Spain, Denmark and Norway. Volvo's motivation for being a project partner is to increase sales of CNG vehicles and gain further experience in the AFV sector.

The total project cost is approx. £2,310,000, the finances mainly being used for fleet purchase. This has been funded by Travel West Midlands (74%), British Gas (15%), Volvo Bus Ltd. (6%) and Energy Saving Trust (5%). Volvo has supported the project financially by discounting the total fleet cost. British Gas have assisted and financed the installation of refuelling points at 2 bus depots. This involved a significant proportion of the total project costs. Energy Saving Trust has part-funded the extra cost of the CNG buses as compared to their conventional diesel counterparts (funded £10k of £40k premium per bus).

PROJECT OPERATION

Unforeseen technical problems were experienced with the vehicle and the fuel economy was not good as initially predicted by Volvo (0.50 kg/km rather than 0.35 kg/km). This was because the fuel economy is very sensitive to drive cycle. Unfortunately, the drive cycle used in the UK was very different to those of previous Swedish vehicle projects using this vehicle. This has had significant impact on economic assessment and also refuelling requirements; the latter have had to be extended to counter the high fuel use.

Higher than expected fuel use has resulted in the vehicles requiring considerably longer refuelling time (60 minutes rather than 10 minutes). Also, two buses have had to be driven 32 km (round-trip) to refuel at the Dudley depot. This has incurred extra unforeseen fuel and personnel costs.

Other technical problems which arose included problems with components and the roof initially leaked rain-water into the vehicle interior. In the first two months, all vehicles needed adjustment to the engines turbo unit. Also, gas cylinder restraints had broken and had to be replaced in all 14 vehicles (which meant 4 days out of service) and gas filters had to be replaced due either to faulty filter or fuel gas composition.

The level of awareness among users before and after project was not quantified. However, anecdotal evidence suggests that gas buses are preferred by drivers and well received by passengers as the vehicles are quieter and perceived to be cleaner than diesel vehicles. This was noted when the CNG fleet had to be withdrawn for 4 days for unexpected maintenance. The replacement diesel buses were compared unfavourably by drivers and passengers alike.

Though the technological problems have caused temporary problems for the CNG buses (components, gas filters, turbo units and gas cylinder restraints), all these initial problems have now been overcome. However, the higher than expected fuel use remains. This has resulted in a higher operating cost as compared to conventional diesel bus operation and remains a significant barrier to the expansion of the CNG fleet in the Midlands.

A legislative barrier for CNG arises from the fact that different regimes are required for certification and inspection of the vehicles. These are not harder to comply with, but they do require learning and a change of practice.

Due to the increased vehicle costs of CNG buses, the *Powershift* subsidy was highly significant in TWM's decision to trial a CNG bus fleet. At the time of the project introduction, the *Powershift* subsidy was for part (25%) of the extra cost of the CNG vehicles as compared to diesel. This has now been increased to 75% for the cleanest vehicle types.

A specifically local barrier to the expansion of the Midland fleet is one of garage space. Travel West Midlands do not have enough space to convert whole garage to CNG even if desired. This is due to the large amount of space required by refuelling equipment. Thus CNG could only be expanded to a maximum of 15% of the fleet.

FINDINGS OF THE PROJECT

The objectives of the project were met; to opt for a complete route conversion to CNG to enable the comparison of CNG and diesel operation. The trial was on a sufficiently large scale to assess the merits of CNG and enough operating experience was gained to enable a direct comparison with conventional bus use.

The main finding of the trial is the higher than expected fuel use. This has required that new equipment be installed to ensure that the whole fleet can be adequately fuelled on a daily basis. This situation has been rectified by installing an extra compressor at the Walsall depot.

As a result of the problems detailed above, Travel West Midlands have opted for a Contract Maintenance Agreement with a Volvo dealer. This reduces uncertainty as regards maintenance costs.

FUTURE PLANS FOR THE PROJECT

TWM do not have plans to expand the fleet at present time. The company plan to continue using the present fleet; the original project being intended to last at least 5 years. If desired, the vehicles can be re-converted to diesel. As all vehicles have engines replaced every 8 years or so, this re-conversion would not add any extra costs to vehicle than would have been required otherwise. Thus residual value of the CNG vehicles is not an issue for Travel West Midlands as they rarely sell vehicles on the second-hand market. (Bus operators are unlike coach operators in this respect.)

PROJECT EVALUATION

The main finding from the project (the higher than expected fuel use) points to the need for reliable vehicle performance data. This should be independent and made widely available to all operators who are considering the use of cleaner fuels. Therefore, information registers (such as the *Powershift* register and Utopia data-bases) should be expanded, updated and distributed widely.

From the experience of this project, TWM believe that central government should continue to provide fiscal measures such as *Powershift* subsidies for vehicle purchase. Also they are of the opinion that vehicle manufacturers have yet to deliver a product (vehicle) that betters conventional vehicles. Further incentives need to be found to increase the motivation and interest in cleaner vehicle production among vehicle manufacturers.

10. Public Transport Executive Perspective: Merseytravel

Contributor: Philip Heseltine, Merseytravel

MERSEYTRAVEL'S EXPERIENCE WITH ALTERNATIVE FUEL VEHICLES (AFV)

This case study provides details of Merseytravel's experience of Alternative Fuel Vehicles (AFVs). It describes the positive action the organisation has taken to improve air quality through both the EU funded JUPITER-2 project and its other environmental initiatives. Innovative bus projects, aimed at field testing a range of alternative fuels, are being introduced into areas of Merseyside as part of the EU Joule Thermie Programme under the EU's Fourth Framework Programme.

Merseytravel aims to encourage the introduction of clean and efficient public transport vehicle technologies and low polluting fuels, within the overall context of integrated packages of measures designed to increase public transport's market share, and will continue to examine the best technologies for public transport in the future.

One of the programmes spearheaded by Merseytravel is 'SMART'; a package of complementary measures aimed at significantly improving the quality and image of bus travel on Merseyside. The programme aims to achieve a significant modal shift and thus reduce energy demand and enhance the environment. The main components of the project include fully accessible low flat floor buses, real time passenger information and selective bus priority measures. The initiative was Merseytravel's contribution to the original JUPITER project, which was jointly funded through the Thermie programme.

The success of the original JUPITER project, has enabled Merseytravel to co-ordinate a new consortium known as JUPITER 2. This is a pan-European initiative being promoted by seven cities across the European Union. The project specifically targets energy usage and associated issues in transport operations. Merseytravel is involved with several co-ordinated JUPITER 2 schemes, which are designed to reflect the Executive's commitment to supporting sustainable economic developments as they incorporate all the high-quality features associated with SMART, but with the addition of more environmentally friendly vehicles. They are being branded 'SMART*eco*'.

AFV PROJECTS IN MERSEYSIDE – JUPITER-2 PROJECTS

There are three SMART*eco* projects being introduced within the Merseyside region. They are centred on Southport (Sefton), Birkenhead (Wirral) and at Allerton (Liverpool). Not only do they employ different vehicle technologies, (Compressed Natural Gas, battery electric and cleaner conventional fuels), they also differ in the types of service provided (Park and Ride, high frequency shuttle services and conventional suburban routes).

HAMILTON QUARTER SCHEME USING BATTERY ELECTRIC MINIBUSES

Hamilton Square, at the historic core of Birkenhead, is a highly congested, urban regeneration area where a package of schemes for the development of the area are being implemented. If the region is to continue to thrive and develop, a realistic alternative to using and parking the private car has to be found. The JUPITER 2 project provides the opportunity to deliver this objective through the introduction of an electric vehicle bus service.

The essential features of the service using electric buses are as follows:

- a route which links the main shopping areas with other transport interchanges and with business, colleges and other tourist attractions;
- a service headway of 7–8 minutes from 07.30 to 18.00 and every 10 minutes to 23.00 with a vehicle requirement of 5 out of 6 vehicles having to be available throughout the day;
- zero emission vehicle at street level which is also quiet and vibration free;
- the vehicles must be of a size to enable safe negotiation of narrow urban streets including pedestrianised areas.

The bus chosen is the Gulliver electric minibus manufactured by Tecnobus of Italy. The design was selected from a short-list of 4 suppliers by Merseytravel. The vehicle has been in production for 4 years since 1993 and there are more than 100 vehicles of this type in service in Italy and prior to the Birkenhead project, only 2 had been exported; now in service in Bristol, UK. Orbis Consultants Limited were appointed to undertake liaison with the DETR regarding UK legislation and the operation of the electric vehicles, while EA Technology of Capenhurst provided expertise on vehicle selection and are now carrying out an evaluation on vehicle performance.

A local bus operator, Crosville, operates the electric minibus service; the contract starting on the 1st October 1998 for a period of 5 years. The non-standard specification of the vehicle means that Merseytravel has leased the vehicles and loan them to the operator. Six vehicles were ordered in March 1998 for delivery in time for the start of the service in October 1998. The vehicles have operated faultlessly since then with minimal dropped mileage due to vehicle faults.

SOUTHPORT PARK AND RIDE USING COMPRESSED NATURAL GAS BUSES

Reduction in car usage in a major retail and leisure centre is the key aim of the Southport Park and Ride scheme. The scheme is a high frequency service using easily accessible low entry buses powered by Compressed Natural Gas. A package of supporting measures including enhanced waiting facilities, and advanced information systems will form an integral part of the proposal.

Park and Ride services were introduced in Southport in July 1993 using conventional diesel buses. The contract was re-tendered in December 1997 specifying the use of low-floor CNG buses. The contract was won by MTL North subsidiary Southport and District to operate the service for the next 5 years and that CNG buses should have been in service by July

1998. In the event vehicles were delivered in January 1999, a consequence of being the first buyers of the Dennis SPD 11.3m vehicle powered by CNG and having to obtain type approval.

The service operates 7 days a week requiring 2 vehicles during the inter-peak, 3 during the peak and 4 at Weekends. When not required for the Park and Ride service, one of the spare vehicles will be used on commercial services in Southport. This will represent the first commercial application of AFVs in Merseyside. The basic operating day is 0730 until 1830 when the last journey departs for the Park and Ride site. The capacity of the fuel tanks is 885 litres at 200 bar pressure giving a range of about 200 miles on a full tank.

ALLERTON SCHEME USING CLEANER CONVENTIONAL FUELS

Merseyside has realised that with over 2,000 diesel buses operating on the road of Merseyside, many of which will be operating for at least the next 12 to 15 years, the cleaning of diesel engine emissions will have a more immediate impact on pollution levels in streets with high concentrations of buses.

The third Jupiter 2 scheme in Allerton will see the introduction of 15 buses fitted with Eminox Continuous Regeneration Traps (CRTs) combined with the use of Ultra Low Sulphur Diesel (ULSD). This is a precursor to introducing Euro 3 standard on all Merseytravel's contracted services at the earliest opportunity.

Barriers to the introduction of AFVs in Merseyside

VEHICLE TECHNOLOGY

The development of AFVs is still in its infancy and knowledge, regarding the construction, operation and maintenance of AFVs is still very limited in the UK. Full size CNG buses have only been available for about 3 or 4 years, while purpose built LPG vehicles have only been available over the last 2 years. EVs are still in the prototypical stage, with the Tecnobus vehicle used in Birkenhead being the only electrically powered bus currently being built in any significant numbers anywhere in Europe. The market has a long way to mature before commercial bus operators will consider these types of AFVs for main stream fleet replacement.

The specification of the gas buses has led to larger tanks being fitted so that they can be operated on MTL North's commercial services in Southport where the range required is 200 miles. For EVs, the range of battery technology is 100 km. The battery exchange of the Tecnobus gives the added flexibility to operate a full days duty with minimal down time. Careful evaluation of the route in terms of gradients and the number of accelerations from stationary has reduced the range of the electric bus to 70km between recharges, approximately 6 hours of running time. The impact of terrain on range is critical and any change of route will require a careful study of the battery exchange schedule if embarrassing failures on the road are to be avoided.

VEHICLE AVAILABILITY

Merseytravel has found it very difficult to find suitable AFVs which could be delivered within the timescales of the project. The CNG vehicles for Southport took more than twice as long to deliver compared with equivalent diesel vehicles. Regarding the EVs, once a suitable vehicle had been found, it took only six months from placing the order to delivery of vehicles and the recharging infrastructure. However prior to placing the order, Merseytravel had to commission consultants, EA Technology, experts in the field of electric vehicle technology to identify suitable EVs which could operate a pre-defined route and schedule. The process of evaluation and final selection of a vehicle took 7 months alone.

The UK and Ireland has the peculiar problem not experienced by other EU countries, namely the need to have right-hand drive vehicles with left-hand boarding. Depending on the circumstances that AFVs operate, it is possible to compromise on the former but not on the latter. This was the case for the EVs for Birkenhead where delivery would have been delayed by 18 weeks and would have added about 10% to the cost of the vehicles had right hand drive been specified. The route being predominantly along one-way streets or pedestrian zones meant that left-hand drive was acceptable and operating experience over the last eight months confirms this to be so.

The introduction of CRT may not be suitable to all types of vehicle and the following problems would limit possibilities:

- Non-turbo charged engines produce too much particulate matter for a CRT to regenerate, thus causing the CRT to block and become ineffective.

- There may be insufficient room or inadequate weight margin to fit the additional or alternative equipment (e.g. coolers, radiators, etc.) associated with Euro 1 and Euro 2 engines.

VEHICLE SUPPORT

Bus operators do not as a matter of course possess the skills necessary to maintain electric vehicles. Merseytravel awarded the maintenance contract and responsibility for battery recharging to Tecnobus themselves. The contract requires Tecnobus to provide two technicians to be based in Birkenhead. At first, they were drafted in from their factory in Italy, which caused some cultural and language problems which affected the reliable operation of the buses. Tecnobus have since recruited and trained a bi-lingual speaking technician who lives locally. Although this does add significantly to overall cost of operating the service, it does ensure that the vehicles operate, are kept roadworthy and a good supply of spare parts is maintained. It is Merseytravel's intention to eventually hand more maintenance to First Crosville.

For the operation of CNG buses, the operator is responsible for maintenance and refuelling of their own vehicles. New procedures addressing issues of health and safety have had to be introduced and appropriate training of staff applied. Both MTL North and Mobil CNG Ltd., to their credit, initiated a comprehensive HAZOP study on both the refuelling plant and the fuel delivery system on the vehicle.

ECONOMIC BARRIERS

As part of their role as Jupiter-2 Project Managers, Transport Travel Research (TTR) are evaluating all three Merseyside Schemes.

The capital costs of vehicles and refuelling infrastructure are a major impediment to private bus operators investing in AFVs for commercial services. The premiums on a CNG vehicle is about £40,000 and for EVs minibus one would expect to have to pay double the price compared with an equivalent sized diesel minibus not taking into account a further £12,000 per vehicle for spare battery and charger.

For Merseytravel the cost per mile for contracting a service using CNG vehicles is 30% higher than it would be for conventionally fuelled buses. Initial results on the operation of the electric vehicles in Birkenhead indicate a fuel cost of 1p per passenger mile, which is significantly lower than diesel buses.

For electric vehicle technology, Merseytravel by leasing and arranging its own maintenance contract avoided a 64% mark-up on the total contract price when considered over the 5 year life of the contract, which bus operators decided to impose to take on the risk of purchasing and maintaining the vehicles themselves.

Any operator contemplating gas powered vehicles needs to invest in its own fast-fill refuelling plant. Anything less would create too much inflexibility in the garage and schedules compared with diesel vehicles. At the moment fuel suppliers are providing attractive leasing deals where refuelling plant costs are recovered through the amount of fuel consumed and the fuel price per litre. This way costs can be spread over a number of years.

The fragmented nature of the bus industry in the UK and its commercial priorities have also made it harder to enter into arrangements with operators, who have tended to concentrate on the bottom line.

POLITICAL BARRIERS

A major regulatory barrier has been the inflexibility of Construction and Use Regulations. In the case of the electric buses, these regulations prevent any standing passengers to be carried because the design only allows for 9 seated passengers arranged in a perimeter layout, despite there being a dedicated standing area in the centre of the low floor section of the bus. The vehicle, by the nature of its design, with low floor and laden with battery packs has a very low centre of gravity. Moreover, the route has a slow average speed and average journey lengths are short, lending itself to standing passengers. The legislation was clearly aimed at van conversions which have high floors and typically 12 or fewer seats.

Merseytravel cannot envisage any further purchases of this type of vehicle until the capacity issue can be resolved, and would certainly not be contemplated by commercial bus operators unless the capacity was similar to an equivalent sized diesel minibuses. Merseytravel are prepared to demonstrate the operation of the vehicle in order to get the legislation changed. Achievement of harmonisation of vehicle Construction and Use legislation across the EC should be a goal.

There is definitely a role for EC, National, Regional and Local Government in implementing mechanisms to facilitate use of AFVs but EC and UK Government are probably the most critical players in relation to policy reform.

PARTNERSHIPS WITH PUBLIC TRANSPORT OPERATORS IN MERSEYSIDE

To date the only AFV vehicles in use in Merseyside, are those being provided as part of the tendered service network. As a matter of course all invitations to tender for the operation of supported services in Merseyside include an option where operators can offer a price for AFVs as well as conventional vehicles. To date no contracts have been awarded for the operation of AFVs when the service has been tendered with the operators being able to choose the vehicle technology. In order to secure the operation of specific types of AFV to operate the various supported services funded through the JUPITER-2 projects, the specific AFV is specified in the tender documents, variations of alternative vehicle technology from that specified being rejected as non-compliant bids.

In the case of the Hamilton Quarter service, the tendering process indicated that operators were only prepared to take the risk of purchasing the vehicles by fully depreciating the cost of the purchase over the length of the contract and increasing the level of cost associated with maintenance. Unknown technology, additional training of maintenance staff and the uncertainty over residual values at the end of the contract inflated the price beyond which could be deemed to be financially justifiable by Merseytravel.

Merseytravel will continually review its contracting procedure to ensure that the most appropriate service in terms of quality, service reliability and environmental performance is offered to the customer. Through effective use of the contracting procedures, Merseytravel will satisfy itself that all operators are in compliance with current statutory environmental legislation with regard to noise, exhaust emissions and the best environmental practices.

RECOMMENDATIONS RESULTING FROM MERSEYTRAVEL EXPERIENCE

Until the cost differentials is reduced by way of increased volume of production, the up-take of these AFVs will rely upon initiatives such as the European funded JUPITER 2 project or the *Powershift* programme which can give the operator a cash contribution of up to 75% of the premium cost.

Though the *Powershift* subsidy has been the greatest assistance, the grant is only available to the vehicle purchaser. This was not a problem for the electric vehicles as Merseytravel could draw down the full grant to offset against the leasing charges for the vehicles. However, schemes which involve the operator buying the vehicles means that the local authority who is promoting and funding the scheme may see little or no grant, unless the grant can be recovered through a reduction in the contract price offered by the operator.

The use of environmentally friendly vehicles and fuels should be encouraged through the taxation system. Preferential V.E.D. and fuel duties related to the provision of more environmentally friendly vehicles should be introduced. Vehicle and fuel manufacturers should also be able to receive tax incentives to develop more environmentally friendly vehicle types. The introduction in January 1999 by Central Government of a £500

reduction in VED for vehicles with lower emissions is very helpful although the saving envisaged in the annual licence fee is not likely to be decisive.

In terms of the operating cost the gap between levels of excise duty on conventional fuels and CNG/LPG has been widened progressively by Central Government. However, the Fuel Duty Rebate available to operators of registered bus services partially negates the effect of this differential.

The creation of the UK National Air Quality Strategy (NAQS) has assisted Merseytravel to form local partnerships whereby the Districts have funded complementary measures to assist our AFV projects. This has included infrastructure and part funding of service contracts as in the case of the Southport Park and Ride which is part funded by Sefton Borough Council. As all local authorities will have a duty to ensure stringent air quality standards as of 2005, they should consider the establishment of low emission zones which only allows access to Cleaner or zero-emission vehicles.

Negotiations with the DETR were started with regard to changing primary legislation in the UK to allow standees in a vehicle with less than 13 seats. The legislation was designed to prevent standing in high floor van based vehicles. However, the Tecnobus is a low-floor vehicle with a low centre of gravity, especially when the batteries are in place. Merseytravel will continue to demonstrate a need to change the law regarding the carriage of standees on vehicles such as Gulliver. Without a change, local authorities in the UK will be deterred from expanding services using small zero-emission vehicles, ideal for urban use.

CONCLUSIONS

Merseytravel has tolerated cost differentials up to 100% as part of a demonstration project. However, these cost differentials will only remain tolerable in the short term as part of projects to demonstrate the applicability and viability of different technologies. It has also been helped by the fact that since the premiums have up to now been partially offset by both European and *Powershift* funding. Moreover, political acceptance for such differentials will only remain if it is clearly demonstrated that the policy is having some demonstrable affect upon the up-take of AFVs in Merseyside on a commercial basis and is helping to drive cost differentials downwards, in much the same way this was achieved with the concept of low-floor buses.

In order for public organisations to obtain best value for money on innovative AFV projects, the public sector needs to have the flexibility of removing the risk away from the private sector. The aim of these projects is to demonstrate the economic and technological viability to the commercial bus operators so that subsequent schemes can be carried out with a greater confidence of cost. Moreover, as more schemes are introduced the more likely that residual values will increase and greater economies of scale will help drive down capital costs.

However, ULSD plus catalyst/CRT is probably the most likely technology to be used in the medium term by commercial bus operators.

Other AFVs have disadvantages which will discourage their take up amongst commercial bus operators. CNG vehicles require heavy tanks on the roof to obtain the range required, leading to extra body strengthening and a consequential increase in unladen weight, while battery durability is still unacceptably poor requiring replacement after 2 to 3 years of operation.

11. The *Powershift* Programme

Since 1996, the Energy Saving Trust have co-ordinated the *Powershift* Programme. The programme aims to help establish a sustainable market for cleaner vehicles in the UK and primarily provides grants to offset the increased capital costs of cleaner vehicles (CVs) specifically vehicles powered by LPG, natural gas and electricity (including battery, hybrid and fuel cell vehicles).

The main objectives of the *Powershift* programme are:

- To reduce directly the emission of carbon dioxide by road transport.
- To establish the basis for a sustainable market for clean fuel vehicles in the UK.
- To demonstrate electric, CNG and LPG vehicles in a variety of operations.
- To provide a basis for vehicle operators to assess the cost of operating clean fuel vehicles.
- To provide vehicle operators with a knowledge base of practical experience of operating CVs.
- To expand the network of CNG and LPG refuelling stations across the UK.
- To help develop and encourage the establishment of public electric vehicle recharging facilities.
- To encourage alternative fuel vehicle manufacturers to reduce the cost of cleaner vehicles.
- To monitor emission and energy consumption of cleaner vehicles.

The *Powershift* programme aims to tackle the barriers preventing the establishment of a sustainable market for cleaner vehicles in the United Kingdom, which are:

- incorrect perceptions;
- lack of objective data;
- high capital cost of clean fuel vehicle;
- limited refuelling infrastructure.

The *Powershift* programme is funded by the Department of the Environment, Transport and the Regions which over the initial 3 year period provided a total budget £6M. It is anticipated that this would provide considerable geared funding from partners to the *Powershift* programme in the form of fuel suppliers, vehicle manufacturers and vehicle operators.

In terms of development of the clean fuel vehicle market the *Powershift* programme is designed to proceed in four recognisable stages.

Stage 1: Establish pilot demonstration projects across UK to raise awareness of clean fuel vehicles. *Powershift* completed Stage 1 during its first year of operation in which 138 clean fuel vehicles in 14 pilot projects were established across the country.

Stage 2: Stimulate supply of clean fuel vehicles and establish seed refuelling infrastructure. Target depot-based fleets where refuelling infrastructure could most easily be supplied. This was done through the development of a procurement consortium consisting of 30 public and private sector fleet operators, and resulted in the awarding of eight separate contracts for the supply of 351 clean fuel vehicles.

Stage 3: Target non-depot-based fleets in and around seed refuelling infrastructure, and to increase supply of clean fuel vehicles. Initially non depot-based fleets to use seed infrastructure provided in stage 2 but as demand grows, fuel suppliers provided with rationale to invest in further refuelling points. *Powershift* has now started Stage 3, although stage 2 will be running in parallel as *Powershift* targets both depot-based and non-depot-based fleets.

Stage 4: Widespread supply of refuelling points and supply of clean fuel vehicles to allow clean fuel vehicles to be a viable option for the private motorist.

Powershift is a high profile programme, generating a lot of interest from local authorities, vehicle manufacturers, private and public sector fleet operators, leasing companies and, to a lesser extent, the general public. The *Powershift* programme has developed a considerable experience in the areas of clean fuel vehicle technology and marketing, a fact which has been recognised by the Department of the Environment, Transport and the Regions and the European Commission.

FUNDING PARTNERSHIPS

During Stage 2 of the programme, the Trust played an active role in the purchase of the clean fuel vehicles by operating procurement groups, called the *Powershift Funding Partnerships*. These are effective at stimulating the vehicle manufacturers into supplying clean fuel vehicles.

The *Powershift* programme targets fleet operators in the public and private sector. The *Powershift* workshops are free and open to a carefully selected audience, mainly fleet operators. Audiences are invited by targeted mailings, and adverts in the trade press. It is expected that 5,000 organisations will be mailed and 1,000 transport professionals will attend the *Powershift* workshops per year.

The programme has been revised significantly during the start of 1998 as the level of interest in clean fuel vehicles has increased, and in order to tackle the objectives of the identified phases in the strategy. With the start of Stage 3, the *Powershift* programme was to be opened and made increasingly accessible to more fleets. To achieve this, a grant application process which is more flexible and ties into the vehicle replacement programmes of fleet operators better has been introduced.

Instead of six monthly grant application deadlines, a rolling application process has been introduced allowing application to be made at any time during the year. The Trust guarantees to provide a decision on funding within a maximum of four weeks. Once a grant has been offered an order must be placed within a three month period, otherwise the offer is rescinded.

POWERSHIFT CLEAN SEAL OF APPROVAL

A number of vehicle manufacturers and converters have jumped on the gaseous fuel bandwagon by supplying products which may not have been designed for use in Europe, not built to the best standards and, in some cases, produced worse emissions than petrol or diesel. Therefore a mechanism was needed to identify which clean fuel vehicles are best, and to encourage the vehicle manufacturers to optimise the clean fuel vehicles they offer.

Powershift has instigated this through the *Powershift Clean Seal of Approval*. This is awarded to a vehicle manufacturer or converter and its individual clean fuel products. The award is based on European, national and industry standards and only those clean fuel vehicles complying with the standards will be eligible for grant funding from *Powershift*. The compliant products will be listed in the *Powershift* Register which is designed to act as a buyers guide for fleet operators.

As a minimum requirement all vehicles awarded the *Powershift Clean Seal of Approval* must:

- Produce no more carbon dioxide than the equivalent petrol or diesel vehicle.
- Produce no more regulated emissions than the equivalent petrol or diesel vehicle.

Grants are then awarded according to how much the Euro 2 emission standard is exceeded.

- Less than 25%, no grant.
- More than 25%, up to 25% grant.
- More than 50%, up to 50% grant.
- More then 75%, up to 75% grant.

During the first quarter of 2000 the grant bands are being revised to take account of the introduction of the Euro 3 emission standards.

THE *POWERSHIFT* REGISTER

The Trust's experience has shown that clean fuels provide the potential to reduce emissions, but it is the technology employed in the vehicle that delivers this potential. Further, with regard to the gaseous fuel vehicles, you can not assume that a particular generic type of equipment will deliver emissions improvements. Therefore, emissions data on each vehicle model is needed to ensure *Powershift* grants are going to those vehicles which provide emissions improvements.

The Register is a growing inventory of vehicle manufacturers, suppliers and emissions data for light duty and heavy duty vehicles which use alternative fuels. The vehicle emissions information is provided by independent emission test facilities in the UK and the rest of Europe. The data include the regulated emissions and fuel economy. The Register also includes carbon dioxide emissions as these are directly related to vehicle efficiency, a major concern of the Energy Saving Trust.

The Trust will only provide grants for clean fuel vehicles listed in the *Powershift* Register, unless an application is for vehicles supplied for the first time to the UK and accepted as a demonstration project. The *Powershift* Register ensures that vehicles receiving *Powershift* grants achieve air quality benefits as well as carbon dioxide emission improvements. The *Powershift* Register will be updated on a quarterly basis and will be made available in hardcopy and through the Trust's web-site.

ACHIEVEMENTS OF *POWERSHIFT*

Considered by fuel sector, LPG has taken a clear lead and can be expected to have developed sufficient refuelling infrastructure and vehicle sales volumes to be sustainable by 2002/3. Natural gas is developing a strong position in heavy goods vehicle markets and offers significant air quality benefits. While electric vehicles have shown good potential, they are being held back by product availability.

The *Powershift* programme is having the effect of helping to establish a sustainable market for LPG, natural gas and electric vehicles sooner than would have otherwise been the case. In so doing the *Powershift* programme will secure significant reductions of carbon dioxide, oxides of nitrogen (NO_x) and particulate matter (PM_{10}) resulting from the additional CVs sold.

The impact of the *Powershift* programme has been assessed using a standard dispersion, S-curve model of the market for CVs. The model critically depends on assessing the final market penetration and the rate of dispersion. The level of final market penetration is assumed to be a function of the refuelling infrastructure established for CVs, while the rate of dispersion is assumed to be dependent on the cost of operating CVs and the level of awareness of CVs in the market.

The progress towards market transformation is assessed by monitoring the changes in the CV market using key indicators, these are:

- increase in number of refuelling stations
- decrease in price premiums of CVs compared to traditionally fuelled vehicles
- increase in number of companies involved in the market
- increased level of awareness of CVs
- increased CV sales per year
- increased CV total vehicle population

These key indicators have been used to measure the overall changes in the market place to date, and to develop projections for continued changes in the market place. The key indicators show, significant market changes have occurred and the programme is progressing towards market transformation. Estimates indicate that the *Powershift* programme will stimulate the purchase of an additional 2.2 million CVs and an increase in the number of CVs on the road of 1.5 million by 2010 than would otherwise be the case under a business as usual scenario.

FUTURE DEVELOPMENTS

As part of the market transformation process the volume of vehicles *Powershift* intends to part-fund will increase during the next three year period. During the first three years, *Powershift* aimed to fund 1,000 clean fuel vehicles which was easily achieved. During the next three years *Powershift* will provide grants for 10,000 vehicles.

In addition to the existing fuels covered by *Powershift*, vehicles powered by hydrogen fuel cells (FCEV) and hybrid electric vehicles (HEVs) may be considered for inclusion in *Powershift* as these types of clean fuels may now offer a viable alternative to traditional fuels. These fuels would be included as demonstration projects, as described in Stage 1 of the *Powershift* programme. The market for these fuels would then be developed through the Stages 1 – 4, with the intention, ultimately, of including vehicles powered by these fuels in the *Powershift* Register.

The future development of the fuel market is expected to result in a number of parallel sustainable niche markets developing, with fuels being selected for the purpose for which they are best suited. Therefore, it is consistent that *Powershift* treats equally all alternative fuels which face barriers to their development yet have the potential to be viable, and to deliver significant local and global environmental benefits.

If successful, by 2010, Powershift has the potential to reduce carbon dioxide emissions by 31 Mt, and NOx and PM emissions by 215 kt and 30 kt respectively through the benefits of transforming the market.

SECTION E:
Vehicle Emission Data

There is obviously a large number of data sources to be considered, especially from the passenger car/light van sector. The results presented are from data that is the most up to date, reliable and relevant. To ensure that it is as valid as possible, the following principles have governed the data selection process:

1. For each vehicle type, all measurements made to the relevant EC legislated test or to a simulation of a recognisable drive cycle
2. Tests made at VCA authorised test centres.
3. Vehicle set-up and build from well established vehicle suppliers, preferably OE vehicle manufacturers.
4. Where available, data is preferred that is taken from comparative tests using the same or similar vehicles in 'back-to-back' tests.
5. Also where available from the Powershift Register, a spread of data results is given to provide a higher level of statistical significance.

TEST DATA ASSUMPTIONS

The following general assumptions apply to the data.

1. Except where indicated, the data is from tests to the EURO Stage 2 drive cycle. (Main difference – Stage 3 includes first 40 seconds after engine start in the measurement).
2. Although the emission legislation relating to buses and trucks is only for the engine and is quoted in gm/kWh, the measured data given has been collected from simulated road tests and is given in gm/km. It is therefore possible to relate more easily to actual driving situations.
3. Vehicles tested are assumed to be new.
4. Diesel fuels are defined in terms of sulphur content as:
   - Euro 2 (BS EN 590 1999) <500 ppm, ULSD <50 ppm, 'clean (city) diesel' <10ppm.
5. Petrol fuels are defined in terms of sulphur content as:
   - Unleaded (EN 228) <500 ppm, 'clean (city) petrol' <20 ppm.
6. No data relating to engine/vehicle durability is quoted.
7. All measured data is ''tank to wheels''. No data is given for the emissions associated with the extraction, refining, distribution, storing of fuels/energy source.

Fuel Duty Rates since March Budget 1999

Fuel	Unit	Duty rate (pence)	Fuel Duty Rebate*	Rebate as % of Duty	Previous Duty Rate	Future Duty Rate
Leaded petrol	Per litre	52.88	38.36	73%	48.63	
Unleaded petrol	Per litre	47.21	32.69	69%	43.42	
Higher Octane Unleaded Petrol	Per litre	52.33			48.76	41.42**
Cleaner Petrol	Per litre	47.21			43.42	
Ordinary Diesel	Per litre	50.21	35.07	70%	44.07	
Ultra Low Sulphur Diesel	Per litre	47.21	35.07	74%	42.25	
Gas Oil	Per litre	3.03				
Fuel Oil	Per litre	2.65				
AVGAS	Per litre	26.44				
Road Fuel Gas	Per kg	15.0	15.0	100%		

* Bus Fuel Duty rebate (FDR) is paid by the DETR to operators of local bus services to reimburse fuel duty paid in running the services. ** as of 1st October 1999.

Energy Content and Greenhouse Gas Production Emissions Associated with Fuels Considered by the Report

Fuel	Net energy content (MJ/kg)	Typical storage pressure (bar)	Density at typical storage pressure (kg/litre)	Energy content (MJ/litre)	kwh/MJ (gms/MJ)	Notes	Non-vehicle CO_2 base (gms/MJ)	Non-vehicle CO_2 future	Notes	Non-vehicle CH_4 base (gms/MJ)	Non-vehicle CH_4 future (gms/MJ)	Notes
Petrol	**43.9**	1	**0.738**	**32.4**		1	**10.3**	**10.5**	7, 8	**0.016**	**0.016**	5, 16
Clean petrol	**43.9**	1	**0.738**	**32.4**		1	**10.5**	**10.5**	8	**0.016**	**0.016**	5, 16
Diesel	**42.9**	1	**0.847**	**36.3**		1	**6.90**	**7.50**	5, 8	**0.015**	**0.015**	5, 16
ULSD	**43.0**	1	**0.830**	**35.7**		1	**7.50**	**7.50**	8	**0.015**	**0.015**	5, 16
CNG	**47.6**	200	**0.143**	**6.81**		1, 3	**6.75**	**6.30**	9, 10	**0.048**	**0.042**	7, 13
LPG	**46.4**	8	**0.508**	**23.6**		2, 3	**7.60**	**7.60**	5, 15	**0.017**	**0.017**	5
Hydrogen	**12.0**					4	**83.7**	**81.0**	7, 11	**0.085**	**0.044**	7, 13
Electricity					0.278		**145.1**	**122.3**	7, 12, 14	**0.422**	**0.088**	7, 14
Methanol												

Non-vehicle emissions include: Extraction, transport, refining, distribution and compression (for gaseous fuels)

Greenhouse gases For conventional fuels (baselines), it is assumed that only CO_2 is the only significant greenhouse gas.
For other options, it is assumed that CO_2 and methane are the main greenhouse gases.
The value fused or the relative Global Warming Potential of methane = 21.
This is the estimated global warming potential (GWP) over a 100 year time horizon that the Framework Convention on Climate Change uses and consequently is used in UK calculations and policy.
(Ref: Department of the Environment, Transport and the Regions, Global Atmosphere Division)

Notes

1 private communication with UKPIA, 1999

2 Source: NGV Factsheet, Version 2.0 July 1998

3 MJ/litre calculated for typical storage pressure

4 Source: Ogden and Nitch, 1993

5 Source: ETSU, 1996

6 Source: ETSU, 1997

7 Source: ETSU, 1998

8 private communication with UKPIA, 2000, estimated from Touche Ross report

9 private communication with UKPIA, 2000, estimated from Energy Trends 1999

10 Includes compression energy required

11 Includes compression energy of 119.9 MJ/GJ – produced from natural gas via reformer

12 Electricity is grid in base, CCGT in future

13 Gas losses associated with high and medium pressure mains assumed

14 Future figure for CCGT is used in order to indicate trend reducing emissions over time

15 Data represents 1991 mix of LPG from refineries and directly extracted in ratio of 41:59

16 CH_4 emissions are assumed to remain unchanged for cleaner fuels for the purposes of the model

Annex E1: Emissions limits for new vehicles – Source: DETR

- The *regulated pollutants* are carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulates (PM).

- Tightening of emission limits for new vehicles is essential to ensure sustained long term improvement in vehicle emissions.

- The emissions limits given in the tables below are the limits which must be met by individual vehicles on their date of first use – which is usually defined as the date the vehicle is first registered at DVLA.

- Most vehicles are also subject to "type approval" i.e. the manufacturer must submit particular model types to be tested and approved to the limits before they are put into production. Type approval limits usually need to be met by new model types one year in advance of first use requirements.

- The emissions limits are those which must be met when the vehicle is tested according to an EU approved "test-cycle".

- "First use" requirements are set out in regulation 61 of the Road Vehicles (Construction and Use) Regulations 1986, as amended. "Type approval" requirements are set out in the Motor Vehicles (Type Approval) (Great Britain) Regulations 1984, as amended, and the Motor Vehicles (Type Approval for Goods Vehicles) Regulations 1982, as amended. These regulations refer to EU directives, or relevant parts of such directives, which contain the emission requirements.

- Pre-1992/4 "Euro 1" limits for passenger cars or light commercial vehicles are not shown in the tables below. However, emissions limits for these vehicles were first set at EU level in directive 70/220/EEC which was adopted in the UK for vehicles first used on or after 1 April 1981. Subsequent directives, also incorporated in UK law, gradually tightened these limits.

- The "Euro 1" limits marked a step change in emission requirements for all vehicles. For petrol-engined cars for instance, they effectively required the fitting of catalytic converters in order to meet the emission limits. Catalytic converters reduce emissions by typically 75%.

- Replacement of existing vehicles by new vehicles meeting ever tighter emissions requirements is bringing sustained improvements in air quality. There are for instance about 8 million cars on the road, now fitted with catalytic converters i.e. about 2 out of every 5 petrol engined cars.

Emission limit levels for new passenger cars[1]										
Pollutant	**CO**		**HC**		**NO_x**		**$HC+NO_x$**		**PM**	
	Type	**Pet**	**Dies**	**Pet**	**Dies**	**Pet**	**Dies**	**Pet**	**Dies**	**Dies**
	g/km3		**g/km**		**g/km**		**g/km**		**g/km**	
31 Dec 1992 (Euro 1) 91/441/EEC	3.16						1.13		0.18	
1 Jan 1997 (Euro 2) 94/12/EC	2.20	1.00					0.50	IDI[4] 0.70 DI 0.90	IDI 0.08	DI[5] 0.10
1 Jan 2001 (Euro 3) 98/69/EC	2.30	0.64	0.20		0.15	0.50		0.56	0.05	
1 Jan 2006[2] (Euro 4) 98/69/EC	1.00	0.50	0.10		0.08	0.25		0.30	0.025	

1. These emission limits apply to passenger cars with 6 seats or less and weighing less than 2.5 tonnes (see also footnote to LCV table below).
2. Subject to confirmation by the EU Commission.
3. g/km = grammes per kilometre.
4. IDI = indirect injection diesel.
5. DI = direct injection diesel.

Emission limit levels for new heavy diesels[1]				
Pollutant	**CO**	**HC**	**NO_x**	**PM**
1 April 1991 (Pre-Euro 1) 88/77/EEC	12.3[2]	2.6	15.8	–
1 October 1993 (Euro 1) 91/542/EEC	4.9	1.23	9.0	0.4
1 October 1996 (Euro 2) 91/542/EEC	4.0	1.1	7	0.15[3]
[1 October 2001 (Euro 3)][4]	2.1	0.66	5.0	0.10[3]
[1 October 2006 (Euro 4)][4]	1.5	0.46	3.55	0.02

1. Diesel engined vehicles over 3.5 tonnes.
2. Grammes per kilowatt hour (g/kWh) – a measurement related to engine power.
3. 0.25g/kWh until 30/9/97 and 0.13 g/kWh from 1/10/01 to 30/9/06 for certain of the smallest engines in this range.
4. Common position on EU Commission proposal agreed by EU Environmental Ministers 21 December 1998. Subject to European Parliament Agreement.
5. From 1/10/09 the NOx limit to be 2.0 g/kWh.

Separate limits, as follows, were agreed by the EU Environment Council on 21 December 1998 (also subject to agreement by the European Parliament) for advanced diesel and gas engines based on a new "transient test cycle" which is designed better to reflect on-road driving conditions. These are as follows:

Date	CO	NMHC[b]	M[c/d]	NO_x	PM[e]	
1 October 2001	5.45[a]	0.78	1.6	5.0	0.16	0.21[f]
1 October 2006	4.0	0.55	1.1	3.5[g]	0.03	

a. Grammes per kilowatt hour (g/kWh) – a measurement related to engine power

b. Non methane hydrocarbons

c. Methane

d. natural gas engines only

e. diesel engines only

f. for certain of the smallest engines in this range

g. From 1/10/09 the NOx limit to be 2.0 g/kWh

Emission limit levels for new light commercial vehicles[1]

Pollutant	CO		HC		NO_x		$HC+NO_x$		PM	
	Type	Pet	Dies	Pet	Dies	Pet	Dies	Pet	Dies	Dies
	g/km		g/km		g/km		g/km		g/km	
> 1.25 tonnes[1]										
1 Oct 1994 (Euro 1) 93/59/EEC	3.16		–	–	–	–	1.13		0.18	
1 Oct 1997 (Euro 2) 96/69/EC	2.2	1.0	–	–	–	–	0.5	0.7	0.08	
1 Jan 2001 (Euro 3) 98/69/EC	2.3	0.64	0.20	–	0.15	0.50	–	0.56	0.05	
1 Jan 2006 (Euro 4) 98/69/EC	1.0	0.50	0.10	–	0.08	0.25	–	0.30	0.025	
1.25 >1.70 tonnes[1]										
1 Oct 1994 (Euro 1) 93/59/EEC	6.0		–	–	–	–	1.6		0.22	
1 Oct 1998 (Euro 2) 96/69/EC	4.0	1.25	–	–	–	–	0.6	1.0	0.12	
1 Jan 2002 (Euro 3) 98/69/EC	4.17	0.80	0.25	–	0.18	0.65	–	0.72	0.07	
1 Jan 2006 (Euro 4) 98/69/EC	1.81	0.63	0.13	–	0.10	0.33	–	0.46	0.06	
1.70 > 3.5 tonnes[1]										
1 Oct 1994 (Euro 1) 93/59/EEC	8.0		–	–	–	–	2.0		0.29	
1 Oct 1998 (Euro 2) 96/69/EC	5.0	1.5	–	–	–	–	0.7	1.2	0.17	
1 Jan 2002 (Euro 3) 98/69/EC	5.22	0.85	0.29	–	0.21	0.78	–	0.86	0.10	
1 Jan 2006 (Euro 4) 98/69/EC	2.27	0.74	0.15	–	0.11	0.39	–	0.46	0.06	

1 Category limits change to 1305 and 1760 tonnes from Jan 2001.

Note: Passenger cars with more than six seats or weighing in excess of 2.5 tonnes are subject to the same emission limits as vans over 1.25 tonnes. By virtue of directive 98/69/EC these passenger cars will meet the same standards as passenger cars with six seats or less from 1 January 2003. Diesel passenger cars over 2 tonnes which are either designed to carry more than 6 occupants or are off-road vehicles are treated as light goods vehicles until 1/1/03.

Table E1: Passenger car < 2500kg and light duty truck class 1 < 1305kg

Legislation

	Emissions gm/km (ECE R.15 + EUDC)				
	CO	NO_X	THC	$THC+No_x$	PM
Petrol Euro 2 Year 1996	2.2			0.50	–
Petrol Euro 3 Year 2001	2.3	0.15	0.20	–	–
Petrol Euro 4 Year 2006	1.0	0.08	0.10	–	–
Diesel Euro 2 Year 1996	1.0			0.70	0.08
Diesel Euro 3 Year 2001	0.64	0.50	–	0.56	0.05
Diesel Euro 4 Year 2006	0.50	0.25	–	0.3	0.025

Measurements at exhaust to Euro 2 gm/km

Fuel type	Reference vehicle	Test source	CO	NO_X	THC	THC + NO_X	PM	CO_2	Econ l/100km (MJ/km)
Unleaded petrol RF 08	Vauxhall Astra 1.4l Manual transmission	Millbrook mbk 990193 April 1999	0.922	0.095	0.213	0.308	–	166.3	7.17 (2.316)
'City' petrol (Sainsbury)	Vauxhall Astra 1.4l Manual transmission	Millbrook mbk 990193 April 1999	1.039	0.095	0.195	0.29	–	164.7	7.19 (2.322)
Unleaded petrol EN 228	Vauxhall Combo 1.4l Manual transmission	Millbrook mbk 990081 Feb. 1999	0.630	0.171	0.091	0.261	–	179.6	7.54 (2.435)
Diesel EN 590	Vauxhall Combo 1.7l Manual transmission	Millbrook mbk 990081 Feb. 1999	0.333	0.515	0.064	0.579	0.035	165.5	6.26 (2.254)
LPG bi-fuel Calor 90-95%	Vauxhall Combo 1.4l Manual transmission	Millbrook mbk 99008 1 Feb. 1999	0.356 0.08 1.71	0.127	0.084	0.211 0.03 0.29	–	153.2 136 204	10.05 (2.372)
LPG Dedicated	No vehicle identified								
CNG bi-fuel 93% methane	Vauxhall Combo 1.4 Manual transmission	Millbrook mbk 990081 Feb. 1999	0.328 0.07 1.62	0.111	0.274	0.384 0.04 0.30	–	142.8 128 192	5.24 kg (2.494)
CNG dedicated	Honda 'Civic' OE conversion	Honda source, tested to Euro 3	0.254	0.101	0.0875	0.1885			
Battery electric	Peugeot 106. 35kW motor 28 kWh NiCd battery	Coventry City trials	0	0	0	0	0	0	0.26 kWh (0.936)
Hybrid electric	Toyota Prius 30 kW motor + gen 20 kWh NiMH battery	BMW internal test	0.3	0.056	0.05	0.106	–	122.1	4.65 (1.502)
Fuel cell Hydrogen	Ford P2000	AEA Journal	0	0	0	0	0	0	(1.13)
Fuel cell Methanol	Ford P2000 estimate	AEA Journal							(1.27)

Table E2: **Panel van up to 3.5t GVW**

Legislation

	Emissions gm/km (ECE R.15 + EUDC)				
	CO	**NO_X**	**THC**	**THC+No_x**	**PM**
Petrol Euro 2 Year 1996	5.0			0.70	–
Petrol Euro 3 Year 2001	5.22	0.21	0.29	–	–
Petrol Euro 4 Year 2006	2.27	0.11	0.16	–	–
Diesel Euro 2 Year 1996	1.5			1.2	0.17
Diesel Euro 3 Year 2001	0.95	0.78	–	0.86	0.10
Diesel Euro 4 Year 2006	0.74	0.39	–	0.46	0.06

Measurements at exhaust to Euro 2 gm/km

Fuel type	**Reference vehicle**	**Test source**	**CO**	**NO_X**	**THC**	**THC + NO_X**	**PM**	**CO_2**	**Econ l/100km (MJ/km)**
Unleaded petrol RF 08	Transit Van 2.01 Catalyst	ETSU report Aug 1997	1.03	0.26	0.25	0.51		239	10.6 (3.42)
'City' petrol	Transit Van 2.01 Catalyst	Millbrook mbk 980451 July 1998	0.94	0.15	0.23	0.38		234	10.3 (3.33)
Diesel RF 73	Transit Van 2.5.1 turbo	ETSU report Aug 1997	0.90	1.00	0.11	1.11	0.2	210	8.08 (2.91)
LPG bi-fuel	Transit Van 2.01 Catalyst	TNO	0.02 0.2 0.54			0.12 0.12 0.45		232 198 232	15.2 (3.59)
LPG dedicated									
CNG bi-fuel	Transit Van 2.01 Catalyst	Millbrook	0.183 0.18 0.8	0.076	0.195	0.271 0.1 0.45		197 197 282	9.3kg (4.43)
CPG dedicated									
Batterey electric	No vehicle identified								
Hybrid electric	No vehicle identified								
Fuel cell	No vehicle identified								

Table E3: **Bus 12m – 44 passenger**

Legislation

	Emissions gm/km (ECE R.15 + EUDC)				
	CO	**NO_X**	**THC**	**THC+No_x**	**PM**
Diesel Euro 2 Year 1996	4.0	7.0	1.1		0.15
Diesel Euro 3 Year 2001	2.1	5.0	0.66		0.10
Diesel Euro 4 Year 2006	1.5	3.5	0.46		0.02

Measurements at exhaust to Euro 2 gm/km

Fuel type	**Reference vehicle**	**Test source**	**CO**	**NO_X**	**THC**	**THC + NO_X**	**PM**	**CO_2**	**Econ l/100km (MJ/km)**
Unleaded Petrol RF 08	No vehicle identified								
'City' petrol (Sainsbury)	No vehicle identified								
Diesel Euro 2	Volvo Olympian double deck	Millbrook Simulated London Bus Route	1.35	15.0	0.64	15.64	0.23	1386 (18.77)	52.14
'City' Diesel	Volvo Olympian double deck	Millbrook Simulated London Bus Route	1.38	14.2	0.64	14.84	0.157	1351 (18.30)	50.83
'City' Diesel + CRT	Volvo Olympian double deck	Millbrook Simulated London Bus Route	0.212	12.53	0.143	12.67	0.028	1343 (18.13)	50.37
LPG bi-fuel	No vehicle identified								
LPG dedicated	DAF GG 170	Millbrook Simulated London Bus Route	0.013	5.4	0.027	5.427	0.017	1309 (20.26)	85.84
CNG bi-fuel	No vehicle identified								
CNG dedicated	Volvo B10L single deck	Millbrook Simulated London Bus Route	0.66	9.92	3.01	12.93	0.05	1343 (23.77)	49.94kg
Battery electric	12m bus estimate – Montmartrobus	ETSU, 1998 + Utopia	0	0	0	0	0	0	(7.00)
Hybrid electric	ALTRA – Ansaldo/Iveco	Utopia project	2.4	3.3	015	3.45	0.03	1012	38.0 (13.68)

Table E4: **Rigid truck 17t**

	Emissions gm/km (ECE R.15 + EUDC)				
	CO	NO_X	THC	THC+No_x	PM
Diesel Euro 2 Year 1996	4.0	7.0	1.1		0.15
Diesel Euro 3 Year 2001	2.1	5.0	0.66		0.10
Diesel Euro 4 (est.) Year 2006	1.5	3.5	0.46		0.02

Measurements at exhaust to Euro 2 gm/km

Fuel type	Reference vehicle	Test source	CO	NO_X	THC	THC + NO_X	PM	CO_2	Econ l/100km (MJ/km)
Unleaded Petrol RF 08	No vehicle identified								
'City' petrol (Sainsbury)	No vehicle identified								
Diesel RF 73	Refuse collection vehicle Seddon Atkinson	Millbrook MBK 970509 Typical refuse collection cycles	3.0	18.8	0.8	19.6	0.36	1562 (120.03)	55.64
'City' Diesel + CRT	Refuse collection vehicle Scania engine + CRT	Millbrook MBK 970509 Typical refuse collection cycles	0.1	14.7	0.09	14.79	0.08	1484 (21.92)	60.9
LPG bi-fuel	No vehicle identified								
LPG dedicated	No vehicle identified								
CNG bi-fuel	No vehicle identified								
CNG dedicated	Refuse collection vehicle Scania	Millbrook MBK 970509 Typical refuse collection cycles	0.3	18.4	6.4	24.8	0.04	1459 (25.61)	53.8 kg
Battery electric	No vehicle identified								
Hybrid electric	No vehicle identified								
Fuel cell	No vehicle identified								

Table E5: **Articulated truck – 38/40t**

	Emissions gm/km (ECE R.15 + EUDC)				
	CO	NO_X	THC	$THC+No_x$	PM
Diesel Euro 2 Year 1996	4.0	7.0	1.1		0.15
Diesel Euro 3 Year 2001	2.1	5.0	0.66		0.10
Diesel Euro 4 (est.) Year 2006	1.5	3.5	0.46		0.02

Measurements at exhaust to Euro 2 gm/km

Fuel type	Reference vehicle	Test source	CO	NO_X	THC	THC + NO_X	PM	CO_2	Econ l/100km (MJ/km)
Unleaded Petrol RF 08	No vehicle identified								
'City' petrol (Sainsbury)	No vehicle identified								
Diesel RF 73									
'City' Diesel	Scania 94L 310 'Safeway'	Millbrook 980350 May 1998 Typical heavy truck cycle	1.2	5.9	0.65	6.65	0.29	777	29.1 (10.48)
LPG bi-fuel	No vehicle identified								
LPG dedicated	No vehicle identified								
CNG bi-fuel	No vehicle identified								
CNG dedicated	ERF EC 12 'Safeway'	Millbrook 980350 May 1998 Typical heavy truck cycle	0.04	0.84	13.6	14.44	0.018	834	31.7 (15.09)
Battery electric	No vehicle identified								
Hybrid electric	No vehicle identified								
Fuel cell	No vehicle identified								

SECTION F:
References and Euro Standards

REFERENCES

ACEA, 1998: *World-Wide Fuel Charter*, European Automobile Manufacturers Association, 1998

AEA, 1998: Automotive Environment Analyst: Feb 1998, Financial Times Automotive

AEA, 1999a: Automotive Environment Analyst, July 1999, Financial Times Automotive

AEA, 1999b: Automotive Environment Analyst, June 1999, Financial Times Automotive

AEGPL, 1998: *AEGPL Strategy Paper on LPG Heavy Duty Vehicles*, Association Europeenne des Gaz de Petrole Liquefies, November, 1998

Atkin & Storey, 1998: *Electric Vehicles, Prospects for battery, fuel cell and hybrid powered vehicles*, Financial Times Automotive Report, 1998

AUKOI, 1999: Questionnaire responses from Tesco, Safeway and Futura compiled by the Association of UK Oil Independents and submitted to the Clean Vehicle Task Force

Boyle, 1996: *Renewable Energy*, Power for a Sustainable Future, Open University Press, 1996

British Gas, 1998: *Natural Gas Vehicle Fact Sheets*, British Gas Technology & Transco, Version 2.0, July 1998

Cuddy & Wipke, 1998: *Analysis of the Fuel Economy Benefit of Drivetrain Hybridization*, National Renewable Energy Laboratory (USA), 1998

Customs & Excise, 1998: *Tariff Notice TN 6/98: Hydrocarbon Oil Excise Duty: Budget 1998 – Revised Definition of Ultra Low Sulphur Diesel*, HM Customs & Excise, 1998

DETR 1998a: *Digest of Environmental Statistics No. 20*, Government Statistical Service, 1998

DETR 1998b: DETR web-page: http://www.environment.detr.gov.uk.airq/aqs/benzene/

DETR, 1998c; A New Deal for Transport, The Government's White Paper on the Future of Transport, DETR, 1998

DETR, 1999: *Environmental Impacts of Road Vehicles in Use*, published by the Cleaner Vehicles Task Force, July DETR, 1999.

DieselNet, 1999: DieselNet web-site: http://www.dieselnet.com/news/9904peugeot.html, April 1999

DVLA, 1998: UK Electric Vehicle Population, Licensed for Use on the Public Highway, DVLA 1998

EST, 1999: Energy Saving Trust: private communication, September 1999

ETSU, 1996: *Alternative Road Transport Fuels – A Preliminary Life-cycle Study for the UK, Volume 2*, ETSU, 1996

EU, 1997: European Union legal text: *Directive Relating to the Quality of Petrol and Diesel Fuels*, 10050/97, 17th September 1997

EVP, 1997: Electric Vehicle Progress, Dec. 15, 1997

FTA, 1999a: Freight Transport Association: private communication, April 1999

FTA, 1999b: Freight Transport Association: private communication, May 1999

Futura, 1999: Futura web-page: http://www.futura-petroleum.com/envn.htm

Greenergy, 1998: Greenergy Presentation to SMMT Light Vehicle Engine Group, 11th August 1998

Greenergy, 1999a: Information taken from web-page: *Citypetrol, Beyond Alternatives*: www.greenergy.com, 1999

Greenergy, 1999b: *Experience with Cleaner Petrol and Diesel, Greenergy response to CVTF Questionnaire*, 1999

Greenergy, 1999c: private communication

Health and Safety Executive, 1999: *Use of Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG) as Motor Fuels*, Report to ACDS Sub-Committees on (I) Petroleum and Other Flammable Substances and (ii) Gas Safety, Health and Safety Executive SPD D3, January 1999

IEA, 1999: *Implementation Barriers of Alternative Transport Fuels*, IEA/AFIS, Innas BV, February 1999

Lane, 2000: *Public Understanding of the Environmental Impact of Road Transport*, Journal for the Public Understanding of Science, due for publication in 2000

LBST, 1999: see http://www.hydrogen.org/accepth2/index.html

LPGA, 2000: Liquefied Petroleum Gas Association, private communication

Mauro, K., 1997: Technology Analyst, Goteborg University, Sweden, private communication

Merseytravel, 1999: information supplied to the Clean Vehicle Task Force by Merseytravel, 1999

NGVA, 1996: information supplied to the Clean Vehicle Task Force by the Natural Gas Vehicle Association

NGVA, 1999: Fred Parker, Natural Gas Vehicle Association: private communication, September 1999

NSCA, 1998: *Cleaner Air: the Role for Cleaner Fuels*, National Society for Clean Air and Environmental Protection, 1998

Potter, S. (1997): *Vital Travel Statistics*, Open University, Landor Publishing, UK

Rupper, 1998: *Where there's fire without smoke*, The Independent, 23 May 1998

Serfas J.A., Nahmias D. and Appleby A.J. (1991): *A Practical Hydrogen Development Strategy*, International. Journal of Hydrogen Energy 16, 551-556

SNM, 1998: *Strategic Niche Management as a Tool for Transition to a Sustainable Transportation System*, Supported by the European Commission, DG XII, within the area 'Human Dimensions of Environmental Change' of the RTD Programme 'Environment and Climate' (May 1996 – October 1998)

Sterlini, 1998: Electricity Association, private communication

Tesco, 1999: John Lucas, Tesco Stores Ltd.: private communication

Q8, 1999: Steve Boocock, Q8: private communication

UKPIA, 1999: Malcolm Watson, UKPIA: private communication

Utopia, 1999: *Urban Transport Options for Propulsion Systems and Instruments for Analysis*, supported by the EC DG VII, 4th Framework Program for Research and Science, Transport Program, 1998 – due to end 2000

Woolf, 1999: Gerry Woolf, Electric Vehicle Association: private communication, September 1999

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