Treatise
training in environmental transport

Cleaner Fuels & Vehicles

A summary of Road Transport Fuels and Technologies from an Environmental Perspective

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Petrol & Diesel

Introduction

Over the last 15-20 years petrol and diesel vehicles have become far cleaner in terms of their 'air quality' emissions i.e. pollutants that affect human health. There have also been some – though less marked - improvements with conventional fuelled vehicles' fuel consumption and CO_2 emissions. [See related Treatise publication "Background: Road Transport Emissions, Legislation and Policies" for further information.]

Many of the developments discussed in this section - such as down-sizing, catalytic converters and the effects of electrical equipment and air-conditioning – also apply to alternative fuel and hybrid vehicles.

Emissions affecting human health have been greatly reduced in recent years but reductions in CO_2 emissions have been small

Down-sizing and Reducing Vehicle Weight

In recent years most European car markets have seen a limited amount of **'down-sizing'**, (people choosing smaller cars), but this remains an area where major improvements could be made. Unfortunately, deep seated cultural preferences and associations with cars - cars as status symbols, reflections of personalities etc – lead to many people still choosing cars that are far larger and more powerful, and therefore less efficient, than they require.

Great gains could be made through 'down-sizing' to smaller &/or less powerful cars

Manufacturers' advertising has traditionally reinforced the situation since large and powerful cars generally sell at a premium and bring greater profit margins. There have, however, been encouraging examples in recent years of some vehicle manufacturers heavily promoting their environmental products and credentials.

Encouraging people to choose smaller, less powerful, more efficient cars when appropriate remains an area with the potential for considerable environmental gains.

Some manufacturers use **aluminium or light-weight alloys** to reduce vehicle weight but in most cases any weight savings achieved through lighter materials have been more than off-set by additional features, in particular safety features such as air-bags, side-impact reinforcing bars.

Use of light-weight materials has generally been offset by the extra weight of increased safety and luxury features

Wasting fuel wastes money

Additional electrical equipment increases fuel consumption because the alternator that recharges a vehicle's battery takes its power from the vehicle's engine. **Air conditioning** also adds significantly to fuel consumption due to the additional mechanical and electrical demand that it imposes. Research published by ADEME in 2003 indicates that using air conditioning on a high setting adds around 25% to a vehicle's fuel consumption and that typical mixed use over a year adds around 5%. Some systems with 'climate control' will run their air conditioning compressors all the time on 'automatic' mode and should be set to 'economy' to avoid this.

The commercial vehicle market is different as minimising fuel costs is already a high priority for most businesses. Further improvements in commercial vehicle efficiencies are therefore likely to stem from technological improvements rather than cultural changes.

Additional onboard electrical equipment and air conditioning has offset much of the potential efficiency gains

Vehicle Technologies to Reduce Air Quality Emissions

The single most important technological development that has contributed to the reductions in vehicle air quality emissions over the last 15 years was the introduction of **catalytic converters**. These were effectively[1] mandated on cars sold in the EU by the introduction of the 'Euro II' standards in 1996.

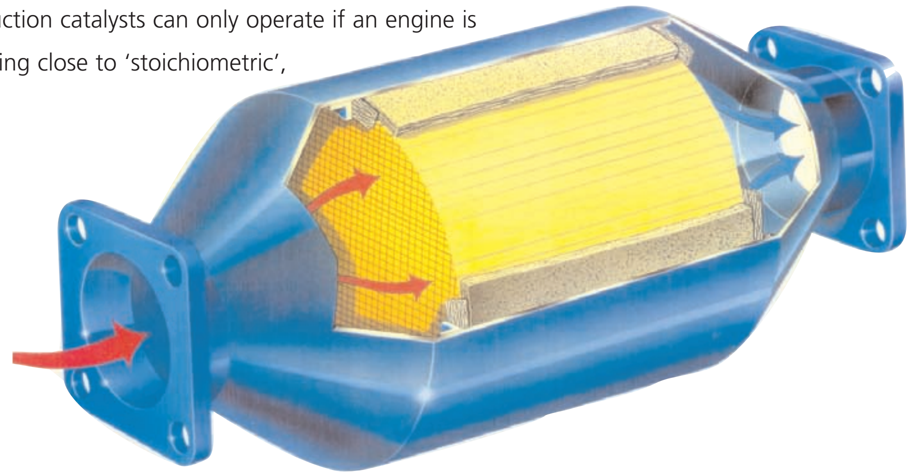
Catalytic converters have brought great reductions in air quality emissions

Catalytic converters, or catalysts, are located between vehicle engines and exhausts. They are ceramic honey-comb structures coated with catalysts usually platinum, rhodium and/or palladium. Their honey-comb structure is designed to have a very high surface area to volume ratio since reactions with the catalysts only take place on the surface.

Petrol engines (spark ignition) have **"3-way catalysts"**, so called because they reduce emissions of 3 pollutants: CO, HC and NO_x. A 3-way catalyst in fact consists of two different parts: A **reduction catalyst** separates harmful NO into benign N_2 and O_2 [$2NO > N_2 + O_2$]. An **oxidation catalyst** then oxidises harmful CO and HC into benign CO_2[2] and H_2O.

Petrol engine catalysts reduce HC, CO and NO_x

Reduction catalysts can only operate if an engine is running close to 'stoichiometric',



A catalytic converter

1 The European emissions standards mandate emissions limits not technologies, but to meet 'Euro II' required the fitting of catalytic converters.

2 CO_2 is of course major problem as it causes global warming, but the amounts produced by the oxidation of CO are generally not considered significant.

which is when the ratio of air to fuel entering the cylinders is exactly that required to give full combustion with no surplus air or fuel. To ensure a petrol engines runs stoichiometric, an oxygen sensor is located immediately downstream (away from the engine) of the catalyst. This sensor feeds in to the electronic control unit which then regulates the amount of fuel injected in to the cylinders.

Diesel engines are designed to run 'lean', which means they run with more air than the stoichiometric ratio. Reduction catalysts cannot operate in lean conditions so diesel engines only have oxidation catalysts. Oxidation catalysts are effective at reducing CO and HC and also reduce some of the particulate matter (PM) but do not reduce NO_x. This is why diesel engines have much higher NO_x emissions than petrol engines.

Exhaust gas recirculation (EGR) is a technique to reduce vehicle NO_x emissions. To understand EGR it is important to remember that NO_x forms when very high flame temperatures cause the oxygen and nitrogen in the atmosphere to combine and that the higher the temperature the more NO_x formation occurs.

Engines with EGR divert some of their exhaust gases, which have low oxygen content since most of this has already been burned, back in to their engine intakes. By doing so EGR reduces peak engine temperatures as there is less oxygen present to burn. This reduction in peak temperature reduces the formation of NO_x.

EGR was first used in petrol cars in the US in the 70s before the fitting of 3-way catalysts made this unnecessary (since 3-way catalysts are very effective at removing NO_x – see above.) In Europe EGR has been fitted to almost all diesel cars and vans sold since the Euro II limits came in to effect in 1996.

EGR slightly increases fuel consumption so manufacturers have been reluctant to fit the systems to heavy duty vehicles (HDVs) as HDV operators put a great emphasis on minimising fuel consumption. However, in order to comply with the 2005 Euro IV standard some HDVs will now be fitted with EGR.

Selective catalytic reduction (SCR) is an even more effective technology to reduce diesel NO_x emissions. SCR is an after-treatment that removes NO_x from exhaust emissions– an advanced catalytic converter – as opposed to EGR, which reduces the formation of NOx. Ammonia (NH_3) or urea is injected in to the exhaust gases upstream of the SCR catalyst. The NH_3 then reacts with NO and NO_2 to give (benign) N_2 and H_2O. [$4NO + 4NH_3 + O_2 = 4N_2 + 6H_2O$].

SCR is already a commercial technology for large stationary diesel engines (where size and weight penalties are less important) and has been fitted to some diesel HDVs. SCR is likely to become widespread from 2006 in order to meet the stringent Euro IV and V diesel HDV NO_x limits.

Diesel particulate filters (DPFs) remove particulate matter (PM) from vehicle exhausts by filtration. They are very effective and often remove in excess of 90% of PM. The particles are collected as soot, which is then removed by thermal regeneration to prevent loss of function of the filter i.e. it is burnt-off to prevent the filter blocking up.

Most diesel engine catalysts only reduce HC and CO

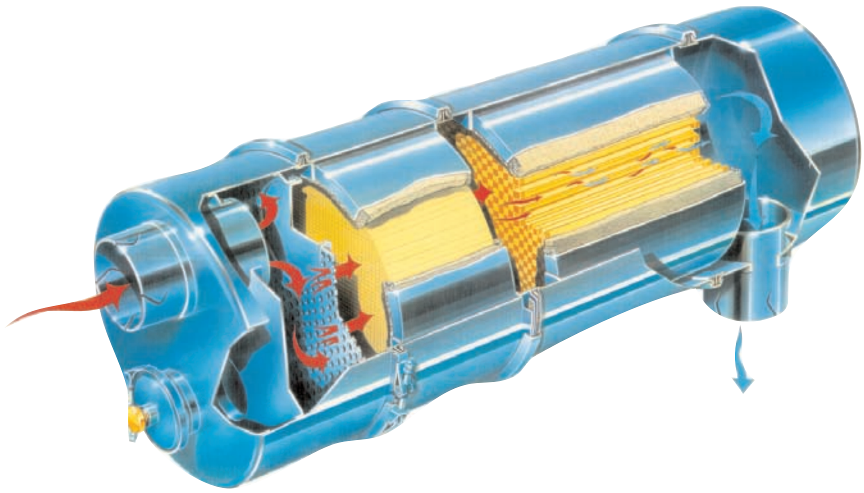
Exhaust gas recirculation (EGR) reduces NO_x emissions by reducing peak flame temperatures

EGR has been standard on diesel cars and vans in Europe since 1996

EGR slightly increases fuel consumption

Selective catalytic reduction (SCR) is an even more effective NOx reduction technique that uses a urea catalyst

SCR is likely to become commonplace on HDVs from 2006



A continuously regenerative diesel particulate filter

Diesel particulate filters (DPFs) are very effective at removing PM

Diesel exhaust temperatures are not hot enough automatically to burn off the soot but DPFs overcome this problem in one of two ways. '**Passive' DPFs** use oxidation catalysts to reduce the temperature at which the soot oxidises, while '**active' DPFs** periodically increase the temperature to a sufficient level. The most common methods of increasing the temperature in an active system are either by periodically burning extra diesel fuel to heat the exhaust or by some form of electrical heating.

The collected PM is then burnt off to prevent it blocking the filters

DPFs are currently only fitted to a minority of new vehicles but are becoming more common. In some European countries DPF grants or subsidies are now available. Many people believe DPFs should be fitted as standard given that they are effective yet relatively inexpensive. Details of the Euro V emissions legislation are yet to be confirmed but it is likely to come into effect in 2008/9 and to include limits that necessitate the fitting of DPFs. Manufacturers already selling cars with DPFs include BMW, Citroen, Mercedes, Peugeot and Toyota.

DPFs are still relatively rare but becoming more common

Retrofitting DPFs to existing vehicles is complicated and is usually only undertaken on heavy duty vehicles.

Increasing Engine Efficiency

Conventional fuelled vehicles have also benefited from **increases in engine efficiency** in recent years. These benefits have accrued particularly to diesel engines and this – along with the relatively low price of diesel in many countries - has contributed to the growing popularity of diesel cars across most of Europe during the last decade.

Engine efficiencies have increased in recent years. Diesel engines in particular have benefited

Since the early 1990s almost all diesels have been **turbocharged,** which greatly improves their efficiency as well as the power output.

Direct injection (DI) has also become increasingly commonplace on diesel vehicles since the late 1990s. With DI the fuel is injected directly into the combustion chamber, rather than into a pre-chamber. Direct injection engines are more efficient than indirect injection and therefore save fuel and reduce CO_2 emissions, but they produce more PM and tend to be noisier. Some direct injection petrol engines have also been introduced in the last 3 years, though these remain relatively unusual.

Common rail direct injection refers to engines that have a single very high pressure fuel line supplying all of their cylinders. The high pressure of the line facilitates better fuel atomisation, which leads to more efficient combustion. Solenoids located at each cylinder very accurately control the quantity and timing of fuel injection, further adding to overall engine efficiency.

Developments include turbo-charging, direct injection, and common rail fuel injection

Low Sulphur Fuels

Low sulphur fuels - usually defined as those with a maximum of 50 ppm (parts per million) sulphur – virtually eliminate emissions of sulphur dioxide (SO_2) and reduce PM emissions.

Furthermore, since sulphur in fuel reduces the effectiveness of three-way catalytic converters and SCR NO_x catalytic converters, the use of low sulphur fuels also reduces emissions of CO, HC and NO_x.

Low sulphur petrol and diesel reduce vehicle emissions

Over the last 6 or 7 years the **sulphur content** of petrol and diesel sold for road use within the EU has been reduced from around 500ppm (parts per million) to an EU wide legislated limit of no more than 50ppm. EC legislation is also in place to reduce the legal maximum level to 10ppm by 2009. Fuels with <= 10ppm are sometimes referred to as 'sulphur free'.

This reduction in fuel sulphur content has brought large air quality benefits although the process to remove the sulphur does itself use energy and therefore adds slightly to fuel production CO_2 emissions.

EC legislation now dictates that all petrol and diesel sold in the EU is low sulphur

Environmental performance

Modern petrol vehicles are far cleaner than their counterparts of only a few years ago. In fact, from an air quality perspective there is now little difference between modern petrol vehicles and their gas powered equivalents.

Modern petrol engines compare well with gaseous fuels

Diesels have also become far cleaner in recent years but most diesels still produce significant levels of harmful NOx and PM emissions unless they have DPFs fitted. Diesels, however, have an inherent CO_2 advantage, so in many situations a diesel with a DPF and with an appropriate strategy to reduce NOx is a good solution from an environmental perspective.

Both petrol and diesel engines are suitable for use with hybrid drivelines, [See Hybrid section of this publication] which offer the potential for significantly increasing vehicle efficiencies and therefore reducing CO_2 emissions.

Petrol and diesel engines can also operate with biofuels [See Biofuels section of this publication], which offer the possibility of further reducing net CO_2 emissions.

Diesels still produced significant PM and NO_x unless they have additional after-treatment fitted

Petrol and diesel engines are both suitable for hybridisation

Hybrids

Introduction

A hybrid vehicle has both an internal combustion engine and an electric motor. Hybrids are cleaner and more efficient than conventional vehicles and their running costs are lower, but they cost more to buy.

Hybrids are no more difficult to drive than conventional cars: they switch automatically between different modes; they never need to be plugged in; and they have automatic transmission.

Toyota introduced the world's first volume-produced hybrid - the first generation Prius - to the Japanese market in 1997, which was followed by the Honda Insight in 1999. More recently there have been new hybrid models from these two manufacturers as well as from Ford, GM and Peugeot-Citroen. Hybrids have received a great deal of attention, initially from the motoring world but more recently from the mainstream media as well. In many countries grants or subsidies are available for hybrids, which has contributed to the vehicles' popularity and led to long waiting lists for several hybrid models in the US and Europe.

Hybrid vehicles are likely to gain market share over the next few years and to remain an important vehicle technology for many years to come. Many commentators believe that in the medium term - perhaps 15-25 years - hybrid vehicles will co-exist alongside hydrogen fuel cell vehicles (FCVs), with FCVs dominating in the longer term.

At present all the hybrid cars available are petrol-electric but it is likely that even more efficient diesel-electric hybrids will soon be introduced, possibly from early 2006. Manufacturers led with petrol-electric models because diesel engines are more expensive and will add to hybrids' price premiums.

Hybrids have conventional engines and electric motors. They are cleaner than conventional vehicles

Hybrids never need to be plugged-in

Many manufactures now produce hybrids

Hybrids are likely to become increasingly popular

Diesel-electric hybrids may soon follow

Hybrid Technologies

Hybrid systems vary greatly in cost, complexity and effect and are often categorised as follows.

Stop-start or micro-hybrids have relatively small electric motors which do not drive their

'Stop-start' hybrids' engines switch off automatically when a vehicle is stationary

A toyota Prius hybrid

wheels directly but which are powerful enough to restart their engines almost instantaneously. This means that a micro-hybrid's petrol engine can turn off automatically when it is stationary (e.g. at traffic lights) and re-start as soon as the driver touches the accelerator, without the driver having to turn the ignition key or even be aware that the engine has stopped.

Stop-start systems are not generally thought of as true hybrids since they are not propelled by their electric motors. They typically bring only modest fuel savings of around 10%, but have the advantage of being relatively inexpensive. An example of a stop-start hybrid is the Citroen C3.

Mild hybrids have the stop-start functionality described above but usually use their electric motors' output for propulsion. Mild hybrids cannot, however, operate solely on electric mode since their motors are not connected directly to their wheels. Instead they provide additional power via their engines during times of high engine load, for example during heavy acceleration. Mild hybrids also benefit from 'regenerative braking': during braking their motors convert some of the dissipated movement energy into electricity, which is used to recharge batteries.

'Mild hybrids' electric motors assist their engines when extra power is required. They also have 'regenerative braking'

Honda's Integrated Motor Assist, found on the Insight and Civic (and Accord in some markets) is an example of a mild hybrid, although Honda's system can also shut-down 3 of 4 engine cylinders to enhance efficiency. The Civic hybrid achieves approximately 25% CO_2 savings compared to a similar non-hybrid.

A Full hybrid system, including Toyota's 'Hybrid Synergy Drive' as seen on the Prius, is capable of propelling a vehicle with just its engine, just the electric motor or both simultaneously.

A 'full hybrid' can be powered by its engine, its motor or both

The Toyota system, much of which is also licensed to Ford for use on the Escape hybrid, uses a continuously variable 'power split' device to send some of the petrol engine's power directly to the wheels and some to the generator. The generator then drives the electric motor, which in turn also drives the wheels. The system is complicated but achieves high efficiency by allowing the engine to run at efficient speeds at all times.

Mild and full hybrids both bring significant savings in fuel consumption and CO_2 emissions

When its full power is not needed to drive the wheels, the motor can turn the generator to recharge the batteries. Batteries are also recharged by regenerative barking. In stop -go traffic and at low speeds - when a petrol engine is least efficient – the engine shuts off entirely and the electric motor, powered by the battery, takes over.

The system employed in the 4 wheel-drive Lexus RX400h is similar but has two electric motors, one for the front wheels and one for the rear.

Whilst none of the hybrids currently available can be recharged externally, **plug-in hybrids** may be seen within a few years. Such vehicles would have larger batteries than current hybrids giving them a much extended electrical range. (The Prius, for example, can only travel a mile or two under 100% battery power). Operators would never be obliged to plug their vehicles in, but if they chose to do so they would have the option of a significant electrical range - perhaps 30 or 40 miles per charge - bringing further fuel cost savings and environmental benefits.

Although current hybrids cannot be plugged-in, plug-in hybrids may become available

The lack of any plug-in hybrids on the market at present may be partly due to the manufacturers' desire to ensure customers differentiate hybrids from pure electric vehicles.

Marketing Hybrids

The Lexus is also interesting from a marketing perspective: whereas the first hybrids were sold largely on the basis of their environmental credentials (think of the 'space age' design of the Insight and the unusual looks of the first generation Prius) the Lexus is being promoted as the high-performance variant of the RX300.

The Honda Accord IMA hybrid (released in the USA in late 2004 but not currently available in Europe) was similarly positioned by Honda as having "power and performance above the current 240-horsepower Accord V6 with the fuel economy of a compact-class, four-cylinder Civic"

These two models appear to point towards a future in which hybrid vehicles become increasingly mainstream and are sold on the basis of their overall performance: what they do rather than what they are.

Some of the most recent hybrid models are being marketed as high performance variants

Environmental performance

At 80g/km the Honda Insight has the lowest CO_2 emissions of any commercially available internal combustion engine (ICE) car worldwide, and at 104g/km the Prius has the lowest of any volume-produced ICE car. It is therefore easy to see why hybrids have caused such as stir in the environmental and automotive worlds during the past 8 years. Indeed the Prius' low emissions are all the more impressive when you consider that it is a 5-seater family car and still has lower emissions than the small diesels cars such as the Toyota Yaris, Citroen C2 and VW Lupo. Most models also have air quality emissions that are well below Europe's most recent 'Euro IV' emissions standard.

There have been several stories that hybrids in 'real world' use do not achieve their low official fuel consumption and CO_2 figures. However this issue is common to all vehicle technologies and it is not yet clear whether there is a particular divergence between hybrid vehicles' official and in-use fuel consumption and CO_2 emissions.

Hybrid vehicles emit less CO_2 than conventional equivalents

Some users claim 'real world' fuel consumption (and CO_2 emissions) are higher than officially claimed

Economics

Hybrids are sold at a premium compared to their non-hybrid equivalents but can bring large fuel cost savings. In most EU countries– as well as many US states and cities– hybrids qualify for purchase grants and/or reduced taxes. For high-mileage users they can make financial sense.

From the manufacturers' perspective the economics of hybrids are unclear, at least in the short term, since many commentators believe the manufacturers make a lost on each vehicle sold. However, production costs are of course expected to fall as volumes increase.

Hybrids cost more but bring fuel and tax savings in most countries. They may lead to net financial savings for high mileage users

Market Penetration

Sales of hybrids remain relatively small compared to conventional vehicles and are now limited by supply rather than demand. Consequently there are waiting lists for most hybrid models in the US and European markets.

Toyota has sold more than 300,000 Prius since the first generation of the vehicle was launched in Japan in 1997, making it by far the world's best-selling hybrid. In 2005 Toyota expects to sell 3500 Prius in the UK.

Although there are waiting lists for most models, hybrid sales currently relatively remain low

LPG

Introduction

LPG, or liquefied petroleum gas, is a mixture of propane (C_3H_8) and butane (C_4H_{10}). The proportions of the two gases vary between countries but propane usually comprises 80-95% of the total. LPG is obtained from two sources: as a crude oil distillate at oil refineries and as a by-product extracted from gas fields along with natural gas.

LPG is a mixture of propane and butane

LPG Vehicles

LPG vehicles are similar to their petrol equivalents but with different fuel storage and delivery systems. Most drivers would not even notice the difference between a vehicle running on petrol and on LPG. LPG is a gas at normal atmospheric pressure but liquefies at only modest pressure (approx. 20 bar). It is therefore stored onboard vehicles as a liquid at approx. 25 bar but is delivered into engine cylinders as a gas.

LPG vehicles are similar to petrol vehicles but have different fuel systems

The majority of LPG vehicles in Europe are bi-fuel: they have LPG tanks and petrol tanks and can change from one fuel to the other at the flick of a switch, therefore removing the danger of being stranded without fuel in an area with poor LPG infrastructure. However, many LPG specialists claim that dedicated (mono-fuel) LPG engines can deliver lower fuel consumption and produce lower emissions.

Most are bi-fuel: they have both petrol and LPG tanks

LPG vehicles' performance and power are similar to their petrol equivalents and in driving there is little discernable difference between the two. An LPG vehicle will typically use 20-25% more fuel than a petrol equivalent and perhaps 30-40% more than a diesel.

Power and performance are similar to a petrol. Fuel consumption is higher than petrol of diesels

Most LPG tanks are cylinder shaped and are located in the boot of a car or in the main body of a van, which has the disadvantage of compromising load space. An alternative is a torroidal (donut) shaped tank designed to fit into a car's spare-wheel well, although in this case the

Refuelling a bi-fuel LPG van

spare wheel is usually carried lose in the boot so boot space is still compromised. In some countries, however, it is legal to carry a self-inflating emergency repair canister instead.

Typically tanks fitted to cars are between 15 and 25 litres and those fitted to vans are often up to 40 litres. LPG buses usually have much larger tanks built into their roofs.

Most petrol vehicles can be converted to LPG but it is generally not practical to convert diesels due to the cost and complications of introducing spark plugs, changing compression ratios etc.

Each after-market conversion should be supplied with an additional warranty to cover any aspects of the manufacturer's original warranty that may be invalidated by the conversion.

LPG tanks are usually cylinder or 'donut' shaped

Most petrol vehicles can be converted to LPG but not diesels

LPG Vehicle Safety

Whilst all LPG vehicles bought from manufacturers have to meet high standards, the quality and safety of after-market conversions varies greatly. A good LPG vehicle will have many safety features including its LPG tank fitted securely enough to withstand the pressures of a high impact crash; a pressure release valve that releases LPG from the tank in controlled bursts in the event of over-heating; fuel pipes made from appropriate materials and secured to the vehicle a safe distance from the exhaust; and a 'gas tight box' enclosing tank valves and venting below the vehicle.

Customers seeking to have a vehicle converted to LPG in the UK should chose a company approved by the LPG Association – www.lpag.co.uk - as this will ensure the company follows appropriate vehicle safety guidelines.

Converted vehicles require an additional warranty

The quality of after-market conversions varies greatly

Environmental performance

It is difficult to generalise about the relative emissions benefits of different fuels since it depends on the specific models of vehicle and equipment concerned. However, compared to its petrol equivalent, a clean LPG vehicle will typically produce 5-10% less CO_2, and slightly lower HC and NOx.

Compared to a diesel equivalent, an LPG vehicle will typically produce approximately the same CO_2 or perhaps slightly more but much less particulate matter (PM) and NOx - unless the diesel has a particulate filter fitted: see Chapter X.

LPG vehicles' environmental advantages over petrol and diesel vehicles has decreased in recent years as conventional fuel vehicles have become much cleaner.

A good LPG vehicle usually has a small emissions advantage over its petrol equivalent

LPG's advantage has decreased as petrol and diesel have become cleaner

Market Penetration

There are approximately 100,000 LPG vehicles in the UK, almost all of them bi-fuel cars or vans, compared to a total of approximately 31 million registered vehicles of any fuel.

LPG is available from just over 1200 service stations in the UK, which is approximately 10% of the total. A map showing the location of these service stations is available at: www.transportenergy.org.uk/tools/refuellingmap/

LPG is available from more than 10% of UK service stations

The numbers of LPG vehicles and service stations grew rapidly in the late 1990s, largely as a result of cuts in LPG fuel duty (tax) in 1999 and 2001 and the availability of Government funded PowerShift grants between 1996 and 2004.

The numbers of LPG vehicles and service stations in the UK grew rapidly in the late 1990s

Economics

Good LPG vehicles typically cost around £1500 more than their petrol equivalents and good LPG conversions costs around the same. LPG costs just over half the price of petrol or diesel per litre but LPG vehicles deliver fewer miles per gallon so overall fuel costs are likely to be approximately the same or slightly less than diesel and approximately 20% less than petrol.

However, as the environmental advantage of LPG vehicles has decreased and as policy has increasingly focused on CO_2 reduction, so vehicle policies have begun to change: LPG vehicle grants ended in March 2005 and in the budget of the same month it was announced that LPG's tax advantage will be reduced by the equivalent of 1p per litre for each of the next 3 years. The future of LPG in the UK is therefore looking uncertain.

Grants have now ended and tax advantages are being narrowed

Natural Gas

Introduction

Natural gas is predominantly methane (CH_4) and is the same as the mains gas that most people are familiar with for domestic cooking and heating purposes. More accurately it is usually comprised of 70-90% methane with ethane, propane and butane forming all but a fraction of the remainder.

Natural gas is a fossil fuel extracted from vast underground chambers, such as those in the North Sea or the Caspian Sea.

Biogas, which is derived from the anaerobic digestion of organic materials, is also predominantly methane. More information on biogas can be found in the Biofuels section of this report.

Natural gas is predominantly methane and is extracted from vast underground chambers

Natural Gas Vehicles

Natural gas vehicles (NGVs) have spark-ignition internal combustion engines (apart from dual-fuel models – see below) and are broadly similar to petrol vehicles but with different fuel storage and delivery mechanisms.

Natural gas vehicles (NGVs) are similar to petrol vehicles but with different fuel delivery mechanisms

Since natural gas does not liquefy under compression, it must either be stored onboard vehicles as very high pressure compressed natural gas (CNG), usually at 200bar, or as cryogenic liquefied natural gas (LNG) below -180C (check). CNG is the more popular of the two options because of the cost and energy required to produce LNG and because of inherent problems of boil-off during the distribution and use of LNG.

Fuel is stored on board as compressed natural gas (CNG) or liquefied natural gas (LNG)

CNG fuel tanks have to be strong to withstand in excess of 200bar pressure, so they are usually made out of thick, heavy steel. LNG tanks are much lighter - in effect they are large thermos flasks - but have to be bulky to contain sufficient insulation to prevent LNG from warming and boiling.

LNG truck fuel tank

NGV fuel tanks are therefore either large or heavy, which means natural gas is best suited for larger vehicles such as trucks, buses or vans. Nevertheless, favourable taxation policies have led to CNG cars being reasonably popular in some countries.

CNG is the more popular option

Natural Gas Systems and Technologies

There are three fuel options for natural gas vehicles: Dedicated NGVs run only on natural gas; bi-fuel NGVs can switch between natural gas and petrol; and dual-fuel NGVs run on a mixture of natural gas and diesel, with the relative proportions of the two fuels changing according to an engine's speed and load. There are advantages and disadvantages in all three options:

Dedicated NGVs are optimised to run on NG, leading to lower emissions

Dedicated (mono-fuel) NGVs can be optimised to run on NG by using higher compression ratios, which generally leads to higher engine efficiencies. This is possible because NG has a higher octane number[3] than either petrol or diesel, which means the compression ratios can be increased without inducing knocking. Dedicated NGVs can also be fitted with catalysts specially designed to capture methane more effectively than normal petrol or diesel catalysts, resulting in lower methane emissions. Most but not all NGVs sold by manufacturers in Europe are dedicated to run on NG.

Bi-fuel NGVs can run on either petrol or natural gas to reduce the likelihood of running out of fuel

Many light-duty NGVs (cars and vans) have **bi-fuel** engines to eliminate the danger of running out of fuel and unable to find a NG refuelling station. This is more likely to be a problem with light-duty vehicles since they have more varied less predictable patters of use than trucks or buses and because cars in particular are not able to accommodate large fuel tanks. However, bi-fuel NGVs cannot be optimised to operate on natural gas and therefore do not show full potential for reducing tailpipe emissions.

Dual-fuel NGVs run on a mixture of NG and diesel

Dual-fuel engines take advantage of diesel engines' inherently higher efficiencies at low loads, which are attributable largely to the lower throttling losses associated with compression ignition engines. The diesel ignites under compression and acts as a pilot ignition to ignite the natural gas. At low loads (e.g. when an engine is idling) duel fuel engines run predominantly or even entirely on diesel, but at higher loads they use a mixture of the two fuels, perhaps as much as 80-90% natural gas at high load. Some diesel is always required for pilot injection since duel-fuel engines ignite by

Environmental performance

Natural gas vehicles are generally very clean in terms of their **air quality emissions** i.e. those that affect human health such as particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO_x) and the carcinogenic hydrocarbons (HC). Their near-zero PM emissions is a particular advantage when an NGV displaces a diesel, which is usually the case with heavy-duty NGVs.

NGVs usually produce less polluting emissions than petrol or diesel vehicles

Methane itself is of course a hydrocarbon, but is usually treated differently from the other HCs since, unlike the other HCs, it is not harmful to human health but it is a greenhouse gas. In relation to NGVs, therefore, people often refer to non-methane hydrocarbons (NMHC) rather than simply to HCs.

[3] A fuel's octane number describes a property of its combustion: the higher the number the less likely it is for combustion to take place ahead of the 'combustion frontier' and the higher compression ratios can be used.

As discussed above, dedicated NGVs usually have methane catalysts designed specifically to capture and remove the relatively high levels of methane that their engines often emit. Methane catalysts cannot be fitted to bi-fuel and dual-fuel NGVs, however, so methane emissions may contribute significantly to these vehicles' overall global warming potential

Methane emissions can be high unless a methane catalyst if fitted

An NGV operating at reasonably high loads will typically produce CO_2 savings of perhaps 20% compared to its petrol equivalent and 5-10% compared to a diesel equivalent. In many urban conditions, however, the diesel engine's inherent efficiency advantage at low loads negates this advantage and NGVs and their diesel equivalents generally produce similar levels of CO_2.

NGVs may reduce CO_2 emissions compared to conventional vehicles. However, for urban use CO_2 emissions are likely to be similar to a diesel's

With regards to the relative CO_2 emissions of diesels and NGVs there are in fact two countering effects: diesel engines are more efficient (kinetic energy out as proportion of the total energy in the fuel consumed) but burning natural gas produces less CO_2 per unit of energy released due to the lower ratio of carbon to hydrogen within its molecular structure.

It is unfortunate that dual-fuel NGVs revert to predominantly diesel operation in urban areas, which is precisely where the air quality advantage of a dedicated NGV would be most important. Care must therefore be taken in assessing a dual fuel vehicle's air quality advantage, particularly if the only emissions data available is cumulative over an entire urban and extra-urban test-cycle.

Dual-fuel vehicles revert to predominantly diesel in low-load urban conditions

Economics

As with other alternative fuel vehicles, NGVs are characterised by higher capital costs but lower fuel costs. Furthermore NGV refuelling stations are expensive – much more so than LPG stations - and are only commercially viable if they refuel a relatively large number of vehicles. This means the introduction of NGVs suffers from the classic problem that fuel suppliers are reluctant to construct refuelling stations until there are sufficient numbers of NGVs and operators are unwilling to purchase the vehicles until there are sufficient refuelling stations.

NGVs cost more than diesel equivalents but fuel costs are lower

Market Penetration

According to the International Association of Natural Gas Vehicles there are nearly 4 million NGVs in use worldwide, of which 1.4 million are in Argentina and 1 million in Brazil.

There are nearly 4 million NGVs in use worldwide

Italy's fleet of 420,000 NGV is by far the biggest in Europe, followed by Germany with 27,000 and Ireland with 10,000. More than 500 public sector NGVs operate in Madrid, including buses and refuge collection vehicles.

There are very few NGVs or natural gas refuelling stations in the UK. However, a grant programme to part-fund the construction of natural gas refuelling stations was announced in August 2005 so it is hoped this situation will improve.

There are few NGVs in the UK but a programme to fund NGV refuelling stations has recently been announced

Natural gas vehicles are available from many manufacturers including Cummins, ERF, Ford, General Motors, Iveco, Volkswagen and Volvo.

Biofuels

Introduction

Biofuels are liquid fuels which are made from a variety of sources of biomass. They can be made from plant materials, certain types of crops and from recycled or waste vegetable oils. When used as fuels for road vehicles, biofuels offer the prospect of low carbon transport, and to a large extent they are renewable and sustainable. By contrast, the conventional transport fuels petrol and diesel, and the road fuel gases such as liquefied petroleum gas and compressed natural gas, are all fossil fuels and have a finite supply.

Biofuels are made from various types of biomass. The main biofuels are biodiesel and bioethanol

Transport biofuels have risen to prominence in recent years. The main reasons for promoting biofuels are:

- To contribute to the security of energy supply;
- To contribute to the reduction of greenhouse gas emissions;
- To promote a greater use of renewable energy;
- To diversify agricultural economies into new markets.

Biofuels can help energy security, reduce greenhouse gas emissions, and offer new markets for agriculture

Based on these considerations, the European Commission issued a Biofuels Directive in 2003, which requires Member States to set indicative targets for biofuels sales in 2005 and 2010. The Directive included "reference values" for Member States to take into account in setting their own targets – 2% by energy content in 2005 and 5.75% by 2010.

An EU Directive sets targets for biofuels use

The main biofuels are biodiesel and bioethanol. Biodiesel is a diesel alternative, whilst bioethanol is a petrol additive or substitute. Biofuels can be used in all types of road vehicles – cars, vans, buses, lorries, and agricultural vehicles.

Biodiesel

Production of Biodiesel

Biodiesel is a general name for methyl esters from organic feedstock. Biodiesel can be made from a wide range of vegetable oils, including rapeseed, and competitor oils such as sunflower, palm oil and soy. It can also be derived from animal fats, grease and tallow. Rapeseed is one of the main oilseed crops grown in Europe, and is the most common feedstock used for biodiesel production. The oil undergoes a chemical process (esterification) to make a methyl ester which has similar fuel specifications compared to fossil diesel. Biodiesel from rapeseed is also known as rape methyl ester (RME).

Biodiesel is made from vegetable oils or from recycled cooking oils

Europe is the largest biodiesel producer worldwide. The total European production in 2004 is estimated at over 1.5 M tonnes, with Germany and France being the largest EU producers. Italy, Czech Republic and Austria are also active in the production of biodiesel.

The vegetable oils used for biodiesel are normal farm crops which can be grown using conventional farming techniques in many parts of Europe. They can be managed to enhance farmland diversity, and the production of biodiesel from vegetable oils provides a useful new market for rural economies.

Biodiesel is derived from oleaginous plants or waste oils

The technology to produce biodiesel from vegetable oils is proven and has been commercially available for several years. For example, biodiesel is produced from rapeseed oil via a simple esterification process by reacting the crushed seeds with a small quantity of methanol in the presence of a catalyst. The resulting biodiesel is normally blended with conventional fossil diesel at the refinery.

The technology to produce biodiesel is commercially available

Biodiesel can also be made from recycled or waste cooking oils, which provides a useful outlet for these oils that may otherwise have to be disposed in an environmentally acceptable manner.

Blends & Engine Warranties

Biodiesel can replace conventional diesel entirely or it can be mixed with it in different proportions for use in compression ignition (diesel) engines. Blending is common in many countries, with 5% blend the most common ie 5% biodiesel; 95% conventional diesel.

Biodiesel is normally used as a 5% blend with fossil diesel

The physical and chemical properties of biodiesel are very similar to fossil diesel and conventional engines require no modification to use 5% blends. Most modern diesel engines could in fact run on blends of up to 30% but care must be taken as use of blends of **more than 5% invalidates many manufacturers' warranties**.

There is no need for engine modifications with 5% blends

Motor manufacturers are normally content to maintain the engine warranty when using a 5% biodiesel blend. Using higher proportions of blended biodiesel may, however, not be supported by the manufacturer. Almost all modern diesel engines will run biodiesel quite successfully, but at higher blends greater than 30% by volume there may be some problems with rubber seals perishing and injectors blocking. It is important that the biodiesel is of high enough quality. EN 590, the European standard for 'normal' diesel allows up to 5% biodiesel. 100% biodiesel must meet the European quality standard EN 14214.

Use of blends above 5% invalidate many manufacturers warranties

Economics & Availability

Producing biodiesel from oil seeds costs about twice as much as diesel from crude oil. The actual costs depend on the relative costs of the biodiesel feedstock and the crude oil. With full fuel duty biodiesel is expensive to buy and a reduction in the duty rate is needed to make it competitive at the fuel pumps. Such duty reductions are common in Europe, and are used as a means of encouraging fuel suppliers to develop biofuel products and to stimulate the market. Biodiesel production is now underway in many European countries.

Biodiesel from oil seeds costs about twice as much as fossil diesel

Biodiesel produced from waste vegetable oil benefits from relatively low feedstock prices. This makes it economic to manufacture with the current duty rate incentives. However, limited supplies of waste vegetable oils and fuel quality issues may limit the contribution that this type of biodiesel can make.

Environmental Performance

The main advantage of using biodiesel as a transport fuel is that it can reduce net greenhouse gas emissions compared to use of fossil diesel. Use of 100% biodiesel (which is rare) would typically reduce net CO_2 emissions by 40-50%, so use of 5% typically reduces CO_2 by 2 – 2.5%. These calculations are based on the complete "life-cycle" of the biodiesel – covering the crop cultivation, biofuel production and use of the biodiesel in a vehicle. In theory, biodiesel can be carbon-free, as the carbon emitted when it is combusted was originally absorbed from the atmosphere during the growth of the oil crop. In practice, however, the carbon savings from biodiesel made from oil crops are limited, because growing and processing the crops requires an input of fossil fuel. Use of biodiesel can contribute to meeting European targets for alleviating climate change.

Use of 100% biodiesel would reduce "life-cycle" CO_2 emissions by 40-50%

Use of 5% blend reduces CO_2 emissions by around 2- 2.5%

Biodiesel can also reduce some tailpipe emissions from road vehicles, although the exact performance of biodiesel can vary depending on the type of diesel vehicle and specification of fuel. Biodiesel provides a European source of supply, making Europe less dependent on imports of crude oil from elsewhere in the world. Biodiesel is safely and easily biodegradable, which is of particular benefit for certain uses such as powering boats in ecologically sensitive inland waterways.

Biodiesel can reduce other tailpipe emissions

Bioethanol
Production of Bioethanol

Currently Brazil and the USA are the world's largest producers of bioethanol as a transport fuel, with sugarcane and corn being the feedstock materials, respectively. In Europe, bioethanol is mainly produced from sugar beet or wheat. Spain, Poland and France dominate the European bioethanol sector with a combined production of over 500,000 tonnes in 2004. Sweden, Austria and Germany are also becoming active in bioethanol production.

Bioethanol is mainly produced from sugar beet or wheat

The feedstocks used for bioethanol production are normal farm crops which can be grown using conventional farming techniques in many parts of Europe. The production of bioethanol from arable crops would provide a useful new market for rural economies, and may enhance rural development.

Bioethanol is manufactured by fermentation of sugar, starch or cellulose feedstocks using yeast. The choice of feedstock depends on cost, technical and economic considerations. The technologies for manufacturing bioethanol from sugar and starch crops are commercially available.

Cellulosic materials such as agricultural and wood wastes and separated domestic wastes are additional options as future feedstocks. However, these materials also have to be hydrolysed before they can be fermented, using more complex processes than for cereals. Cellulosic materials are seen as long-term potential sources of sugars for ethanol production and their use may offer greater CO_2 reduction. The technologies for bioethanol manufacture from these materials are immature, however, and will probably take at least 5-10 years to reach commercial production.

Technologies for producing bioethanol from sugar beet and wheat are commercially available

Bioethanol can also be made from cellulosic materials, but the technologies are not yet commercially available

Blends & Vehicle Warranties

Bioethanol can be used as a 5% blend with petrol under the European quality standard EN 228 and at such a blend no engine modifications are required. Vehicle owners running their cars on bioethanol blends should adhere to the recommendations of the individual car manufacturers. Some vehicle manufacturers specify that the maximum bioethanol blend in petrol should be no more than 5% bioethanol by volume, whilst others specify a maximum bioethanol blend in petrol of 10% by volume. If the stated maximum blend is exceeded a vehicle's warranty will be invalidated.

Bioethanol can be used as a 5% blend with petrol

100% bioethanol can be used in modified, spark-ignition engines, although cold starting requires the addition of a small amount of a volatile fuel component – usually petrol.

The 5% blend of bioethanol in petrol by volume converts into 3.4% by energy content because the energy content of bioethanol is only about two-thirds that of petrol.

The use of flexible fuelled vehicles (FFVs), which are specially designed to utilise a range of bioethanol concentrations, provide an alternative approach. Ford sells a bioethanol FFV Focus in Sweden. Saab and Volvo also plan to introduce bioethanol FFVs, which can operate with a blend of 85% bioethanol and 15% petrol.

A 5% blend can be used in normal engines with no modifications

Modifications Required for Blends >5%

The **octane number** of a petrol fuel is defined as a measure of the resistance of the fuel to abnormal combustion - known as "knocking". The higher the fuel octane number, then the less likely it becomes that the engine will be susceptible to "knock". The "knocking process" is caused by the incomplete combustion of the petrol fuel in the engine cylinder, which causes a sudden knock or blow to the piston, which over a period of time will seriously damage the vehicle engine. By adding a 10% bioethanol blend to petrol, the octane number of the petrol fuel is increased by two points. Therefore bio-ethanol is termed as an "octane enhancer".

Blends higher than 5% require some engine management modifications

The **air:fuel ratio** that is required for petrol in order for complete combustion with no excess air is about 14.6. This means that 14.6 kg of air is required for the complete combustion of 1 kg of petrol fuel.

A 10% bioethanol blend of fuel will normally have an oxygen content of about 3.5% and the oxygen in the bioethanol affects the air:fuel ratio of engine operation. Therefore, it is usually necessary for engines to have the air:fuel ratio reduced in order to take into account the oxygen content that is present in the bioethanol blend.

The engine management systems that are fitted in most modern motor vehicles will electronically sense and change the air:fuel ratio in order to maintain the correct ratio when bioethanol fuels are added to the engine. For some vehicles, the maximum oxygen content that can be compensated for is 3.5% oxygen (ie a 10% bioethanol fuel blends). Older vehicles are usually not fitted with engine management systems, instead they operate with a normal fuel carburettor system. Thus, the carburettor air fuel mixture must be adjusted manually, in order to compensate for the increased oxygen content that is present in bioethanol blended fuels.

The engine management system will need to cope with the higher oxygen content of the fuel

It may be necessary to change a vehicle's **fuel filter** more often because bioethanol blends can loosen solid deposits that are present in vehicle fuel tanks and fuel lines.

Fuel filters may require additional cleaning

Bioethanol blends have a higher latent heat of evaporation than 100% petrol and thus bioethanol blends have **poorer cold start** ability in winter. Therefore some vehicles have a small petrol tank fitted containing 100% petrol for starting the vehicle in cold weather.

Cold starting may be a problem

Vehicle Warranties

Some vehicle manufacturers specify that the maximum bioethanol blend in petrol should be 5% bioethanol by volume, whilst others specify a maximum bioethanol blend in petrol of 10% by volume. Vehicle owners should adhere to these recommendations since exceeding the recommended limits would invalidate vehicle warranties.

Manufacturers warranties need to be checked before using blends >5%

Fuel Handling

A further issue is the water-attracting properties of bioethanol, which can cause problems with fuel handling, storage and distribution. Bioethanol blended with petrol cannot be stored in conventional floating roof storage tanks, and it is difficult to distribute through the existing pipeline infrastructure due to the potential for contamination of jet fuel. As a consequence, blending tends to be done at the distribution terminals. Problems with meeting fuel vapour pressure specifications when using bioethanol also creates additional costs for the fuel producer.

Bioethanol must be handled carefully

Economics & Availability

Producing bioethanol costs about 2-3 times as much as petrol from crude oil depending on the relative costs of the bioethanol feedstock and the crude oil. The production costs are also influenced by the high capital cost of the production facilities for hydrolysis and fermentation. With full fuel duty bioethanol is expensive to buy and a reduction in the duty rate is needed to make it competitive at the fuel pumps. As with biodiesel, such duty reductions are common in Europe, and are intended to be used as a means of encouraging fuel suppliers to develop bioethanol and to stimulate the market. Bioethanol production is now underway in many European countries.

Bioethanol costs 2-3 times as much as petrol

Environmental Benefits of Bioethanol

The main advantage of bioethanol is that it offers net greenhouse gas emission reductions. For 100% bioethanol the reductions are typically 50-60% on a "life-cycle" basis compared with conventional fossil fuels. The benefits deriving from the use of blends are of course less. For example 5% blends would bring approximately 2.5-3% net reductions.

Bioethanol reduces "life-cycle" CO_2 emissions by 50-60%

In common with biodiesel, the climate change benefits will depend on the feedstock used for ethanol production. The 50-60% greenhouse gas emissions savings on a life cycle basis are from bioethanol made from both sugar beet and wheat. If cellulosic materials are used, then the net greenhouse gas savings can be greater – perhaps as much as 75-80%. It is the low energy inputs to cellulosic crop production and more efficient / renewable based processes that are the key to reducing emissions.

It is important to recognise that the bioethanol production process is itself energy intensive and requires a significant input of conventional fossil fuel energy. However, it is clear that use of bioethanol can contribute to meeting targets for alleviating climate change.

Bioethanol can also reduce emissions of some tailpipe emissions from road vehicles, although the exact performance of bioethanol can vary depending on the type of petrol vehicle and specification of fuel

Bioethanol can reduce other tailpipe emissions

Biogas

Biogas is a mixture of gases, predominantly methane and carbon dioxide, that result from the anaerobic decomposition of waste such as domestic, industrial and agricultural sewage.

Biogas is predominantly methane and is produced from decomposition of waste materials

Biogas is produced at more than 4000 sites in Europe, mainly landfill and sewage plants and is normally used to power gas turbines to produce electricity. However, if it is upgraded to natural gas quality – at which point it is sometimes called Substitute Natural Gas (SNG) - it can also be used to power vehicles.

Upgrading biogas involves removing CO_2, which typically constitutes 30-45% of biogas but less than 1% of natural gas, as well as other trace gases and impurities such as H_2S.

Biogas must be upgraded for vehicle use

Environmental Performance

Biogas is effectively natural gas so vehicles fuelled by biogas produce similar tailpipe emissions to other NGVs [see Natural Gas section of this publication for further information]. However, use of biogas brings additional major benefits in terms of greenhouse gas emissions because it is a renewable fuel and as such the carbon dioxide released when it is burned would only recently have been removed from the atmosphere. Furthermore, use of biogas ensures that methane (a potent greenhouse gas) produced at landfill sites and sewage plants is captured rather than being allowed to escape to atmosphere.

Using biogas can bring major reductions in greenhouse gas emissions

Market Penetration

Biogas has been used as a vehicle fuel in Sweden, where a national biogas fuel standard dictates that the fuel must constitute a minimum of 95% methane and more recently in Switzerland. However, numbers remain low, with probably only a few thousand vehicles fuelled by biogas worldwide.

To date only a few thousand vehicles worldwide run on biogas

Battery Electric Vehicles

Introduction

Electric vehicles (EVs) produce no emissions at the point of use, they are near-silent and are cheap to run. The first EVs were produced in the 1830s and the vehicles have been in use in various forms ever since.

In the 1990s many manufacturers had major EV programmes and new models were launched including from Citroen, Ford, Honda, GM, Peugeot, and Toyota. However, even after considerable research effort, modern EVs have much reduced range and performance compared to petrol or diesel vehicles and sales of EVs have remained relatively low. Since the late 1990s much interest and most research funding has been switched from pure EVs to hybrid vehicles, which combine electric motors with internal combustion engines to give more power and greater ranges.

Nevertheless, EVs are very well suited to some applications and they can deliver major environmental benefits so they should not be overlooked.

Electric vehicles (EVs) produce no tailpipe emissions and are near-silent

Many manufacturers launched new EVs in the 1990s

EVs have reduced performance compared to conventional vehicles but are suitable for some applications

Battery Properties

The most important technical difference between EVs is their battery type. The ideal EV battery would meet many different performance criteria: It would have **high specific energy** (the amount of energy stored by mass, measured in kWh/kg), **high energy density** (the amount of energy stored by volume, measured in kWh/m3) and **high specific power** (the peak power output available, measured in W/kg). It would have a **long cycle-life** (i.e. it could be discharged and recharged many times without significant deterioration in its performance), a **quick re-charge time** and would be **deep cycle** (i.e. could be regularly discharged to near-empty without loss of function). It would also operate over a **wide temp range** and would be **safe**, **recyclable** and **cheap**.

No batteries meet all of the above criteria so for an EV manufacturer choice of battery always involves a degree of compromise. The most common EV battery types are summarised below.

EV batteries have to meet many different criteria: The perfect battery does not exist

Types of Battery

Lead-acid batteries were used in the first EVs 170 years ago and are still the most common battery in use on EVs today. They are inexpensive, easily recyclable, and most lead-acid EVs can be recharged in approximately 6 hours. Most lead-acid batteries are aqueous (liquid) and have to remain upright to prevent leakage, but there is also a ‘gelled lead acid’ non-aqueous version that does not have to be mounted upright.

However, lead-acid batteries have low specific energy and low energy density so they are large and heavy and only provide a limited range. Lead-acid batteries should not be discharged to more than 80% ‘depth of discharge’ (DOD) i.e. to less than 20% of their capacity, as doing so shortens their operational life. Lead acid batteries are used on many EV including the REVA, GM’s EV1 (Mk 1) and several electric mopeds.

Lead-acid batteries are cheap and well-proven but give limited range

Nickel Cadmium (Ni-Cd or nicad) batteries have also been in use for many years. They have a higher specific energy (around 55 Wh/kg) and higher energy density than lead acid batteries. Ni-Cds also have long cycle lives and can be discharged to 100% DOD with no negative effects.

Although Ni-Cd batteries are recyclable, concerns over the possibility of cadmium (a heavy metal) contaminating landfill sites led to an EC directive in 2002 that bans the sale of Ni-Cd batteries for new EVs from the end of 2005. Ni-Cd batteries are also expensive. For example the Saft Ni-Cd batteries that power most electric Peugeots and Citroens are usually only available on a lease from PSA and cost approximately ?200/month.

Ni-Cd batteries give a longer range than lead-acid but are expensive and are soon to be banned in the EU

Nickel metal hydride (Ni-MH) batteries have a high specific energy of approximately 90 Wh/kg and very long cycle lives. They are recyclable and are relatively benign to the environment since the anode is made of an alloy of non-heavy metals, so they do not present particular dangers of land or groundwater contamination.

Ni-MH batteries were used on GM's EV1 to give the vehicle a range of approximately 250km per charge and on the electric Toyota Rav4 which has a range of approximately 200km. Smaller Ni-MH batteries are also used in the Honda Insight and Toyota Prius hybrids and much smaller Ni-MH units are used for applications such as mobile phones and laptops.

Ni-MH batteries give even longer range and are used in many modern EVs

Ford briefly used **sodium sulphur** batteries on its Escort-based Ecostar van in the mid1990s. However these batteries are no longer used for vehicles due to safety concerns, since they operated at 300C and sodium explodes on contact with water.

Sodium sulphur batteries are no longer used on EVs due to safety concerns

Lithium ion batteries have very high specific energy of approximately 150 Wh/kg and very long cycle lives. Several prototype Li-ion EVs have been produced including a Ford Ka in 2000 which had a range of 150-200km and a top speed of 130km/h. There was also proto-type Li-ion Mitsubishi Eclipse in 2003 and even an 800bhp 230mph Li-ion prototype called 'Eliica' in 2004.

Unfortunately, for the time being Li-ion batteries remain prohibitively expensive for use in production vehicles and none are expected in the near future.

Lithium-ion batteries give the highest range and excellent performance but are expensive

Ford Th!nk electric vehicles

Environmental performance

Electric vehicles produce zero tailpipe emissions, which makes them a particularly attractive environmental proposition for busy urban areas where poor air quality often leads to health problems.

EVs can bring great benefits to urban air quality

Peugeot 106 Electric being re-charged

A full analysis of EVs' environmental benefit must, however, also consider the emissions associated with the production and supply of the electricity used to recharge the vehicles.

Emissions from electricity generation must also be considered

In many countries this is easy to calculate for CO_2 since figures are available for the average CO_2 produced per kWh of electricity delivered.

In the UK, for example, the figure is 430g CO_2/kWh delivered. For small electric cars or car-derived vans such as the Peugeots 106s and Citroen Berlingos this translates to approximately 80-90 g CO_2/km, which is on a par with the 2-seater Honda Insight hybrid and is considerably better than any conventional petrol or diesel vehicle. In France, where most electricity is generated by nuclear power stations, or in Switzerland where most is from hydro or nuclear the CO_2 emissions attributable per km would be far less.

In many countries such an analysis still shows EVs to be very low carbon

Batteries can have a high environmental impact due to the energy required to produce them and because of the potential for contaminating land or groundwater upon their disposal. However, the most popular EV batteries (lead-acid and Ni-MH) are both readily recyclable and the EC End of Life Vehicle Directive (2000/53/EC) dictates that they must be recycled.

In Europe EV batteries must be recycled

Economics

As with many alternative fuel and vehicle types, the economics of EVs are characterised by higher capital costs but lower running costs: Recharging an EV is relatively cheap and in most countries EVs benefit from lower sales and/or annual taxes. There is some uncertainty about battery lifetimes and replacements are expensive, but Ni-MH batteries in particular have very long cycle lives and recent experience suggests they are likely to last as long as the vehicles themselves.

EVs have a higher capital cost but lower running costs

The question of the financial viability of EVs needs to be considered in the wider context of whether the vehicles are practical for a specific use and how they will fit with and complement an operator's other vehicles. For example, it is unlikely that an EV would be appropriate for a family as their only car, but as an urban delivery vehicle, a city-based pool car or a private car to be used for commuting and shopping an EV may well be a practical and financially viable option.

It is generally accepted that in the foreseeable future EVs will only be appropriate for specific niche markets.

The financial viability of EVs depends on an operator's specific circumstances and requirements

Market Penetration

Sales of EVs in the UK remain very low with at most a few hundred road-licensed modern electric vehicles and only 12 known public recharging points.

Sales in the UK remain very low

Fuel Cell Vehicles

Introduction

A fuel cell is an electrochemical device that combines hydrogen (H_2) and oxygen to produce only water, heat and electricity. The fuel cell is a very promising technology that is expected to provide a clean and efficient source of power for many applications, including transport.

Almost all vehicle manufacturers are involved with major fuel cell research programmes but most believe fuel cell vehicles (FCVs) are unlikely to become commonplace until around 2020 at the earliest.

Fuel cells run on hydrogen (H_2) and produce electricity

Major research programmes are underway to commercialise fuel cells

Workings of a Fuel Cell

A fuel cell consists of an anode and a cathode with an electrolyte sandwiched between them. The electrolyte has the unusual property of allowing (positively charged) ions to pass through it but not (neutral) molecules or (negatively charged) electrons.

H_2 molecules are supplied to the anode side of a fuel cell, where a catalyst, usually platinum, splits each molecule into two H+ ions and two electrons. The H+ ions pass freely through the electrolyte to combine with oxygen molecules at the cathode, but the electrons are blocked. The electrons run through an external circuit from the anode to the cathode where they rejoin the H_2 ions and oxygen molecules to form water. This movement of electrons through the external circuit is a direct current, which can be used to power the electric motor of a fuel cell vehicle.

The only emission from a fuel cell is water

Each fuel cell produces approximately 0.7 volts but cells can be connected together in series to produce fuel cell stacks of any required voltage.

Fuel cell stacks can provide any desired voltage

Fuel cells need a continuous supply of hydrogen when they are operating. The oxygen required for the reaction simply comes from the air.

DaimlerChrysler Citaro fuel cell bus

Types of Fuel Cells

There are several different types of fuel cell, distinguished principally by the composition of their electrolyte. The proton exchange membrane (PEM) fuel cell is most suitable for road transport applications because of its high energy density, relatively low operating temperature and short warm-up times.

Refuelling Options

There are different options for storing hydrogen onboard a vehicle. One option would be to refuel FCVs with a liquid containing a high proportion of hydrogen, for example methanol or a hydrocarbon similar to gasoline.

Liquid fuels would be easier to distribute and supply as they are energy dense, do not need to be pressurised and because existing vehicle refuelling infrastructure (tankers, service stations etc) is designed for liquid fuels. Onboard storage is also easier with liquid fuels as vehicles don't require pressurised fuel tanks and because high energy density makes high vehicle ranges easy to achieve.

Fuel cells, however, must be supplied with pure gaseous hydrogen so if a liquid were used FCVs would have to be fitted with onboard reformers to extract the H_2 from the liquid. Reformers would add to vehicles' weight and cost and would create gaseous by-products forming new categories of vehicle emissions. Use of liquid fuels would also exclude the possibility of moving to a genuine 'hydrogen economy' using renewably produced hydrogen.

It therefore seems likely that FCVs will be refuelled with hydrogen and that the hydrogen will be stored onboard as a gas under high pressure.

There are several options for storing H_2 onboard vehicles

A liquid fuel containing H_2 would be easier to distribute but would require additional reformers onboard vehicles

Refuelling with pure H_2 would be the environmentally preferable option

Peugeot 106 Electric being re-charged

Environmental Performance

Fuel cells vehicles refuelled with hydrogen produce no tailpipe emissions other than water vapour, so have the potential to bring great environmental benefits. Initially most of the hydrogen is likely to be derived from natural gas by a process that produces CO_2. Nevertheless, due to fuel cells high efficiency – this would still bring a major reduction in total ("well-to-wheel") CO_2 emissions.

In the long-term, H2 might be produced by electrolysis using renewably generated electricity and distributed by pipeline to supply fuel cells for vehicles and domestic use. This would herald the arrival of the 'hydrogen economy' with its promise of virtually CO_2-free energy.

Fuel cells powered by renewably produced H_2 promise CO_2-free energy

Economics

The economic viability of FCVs is dependent on greatly reducing fuel cell production costs and on developing a commercially viable refuelling infrastructure.

Market Penetration

Several hundred demonstration FCVs operate worldwide including three fuel cell buses in London that are part of the EC funded Clean Urban Transport for Europe project involving 30 fuel cell buses in 10 cities.

FCVs are currently at demonstration stage

Hydrogen internal Combustion Engines

H_2 can also be burned in internal combustion engines (ICE) that are very similar to petrol engines, but which produce zero emissions of tailpipe CO_2, CO and HC (except for very small quantities deriving from engine lubricants). Hydrogen ICEs bring some of the advantages of FCVs but in a technology that is already well-proven and accepted by consumers.

Some vehicle manufactures believe H_2 ICE vehicles will help bridge a gap towards a longer term FCV future by creating demand for H_2 as a fuel, thereby leading to the development of a H_2 refuelling infrastructure that will fuel FCVs in the longer term. BMW takes this a stage further and believes that the long-term future lies with H_2 ICE vehicles rather than FCVs.

Most manufacturers, however, believe that the long-term future lies with FCVs rather than H_2 ICEs, principally because FCVs are far more efficient.

H_2 can be used to fuel internal combustion engines (ICEs)

H_2 ICEs could form a 'bridge' towards a fuel cell future

H_2 ICEs are not as efficient as fuel cells