Environmentally-friendly Road-transport Technologies

Increased concerns about the level of atmospheric pollution, especially carbon dioxide, oxides of nitrogen and particulate emissions, are forcing the transport sector, including aviation, to radically assess how it can reduce the generation of pollutants. It is estimated that approximately 25% of the UK’s total carbon emissions are generated by transport, with road vehicles accounting for 85% of this and passenger cars generating about half of all carbon emitted by the transport sector. Mandatory EU limits on oxides of nitrogen from 2010 will have a significant effect on the operation of future transport systems; noise is also a significant nuisance that needs to be minimised.

This briefing discusses some of these issues. It seeks to show how developments in petrol- and diesel-engine technology, as well as hybrid power systems, modern power-train design, and renewable energy resources could help reduce the emission of pollutants. The impact of legislation is discussed too.

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1.0 Introduction

Increasing concerns about the level of atmospheric pollution, especially carbon dioxide, oxides of nitrogen and particulate emissions, are forcing the transport sector, including aviation, to assess how they can reduce the generation of pollutants. It has been estimated that approximately 25% of the UK’s total carbon emissions are generated by transport, with road vehicles accounting for 85% of this and passenger cars generating about half of all carbon emitted by the transport industry. Mandatory EU limits on oxides of nitrogen from 2010 will have a significant effect on the operation of future transport systems; also, noise is a significant nuisance that needs to be minimised.

There is an urgent need to develop petrol and diesel engines commercially that run more leanly than they do now and yet retain driveability. Alternative fuels such as bio-diesel, methane and hydrogen can potentially have a significant effect on emission levels, but ultimately it may well be that hybrid power systems, in which a conventional internal-combustion engine is combined with an electric motor, will provide an answer to pollution levels in cities. Fuel cells have their part to play in this too.

Ultimately, public transport has to be made more attractive to users so that there is less need to use a car in the inner city, where it causes congestion and pollution. These and other issues are addressed in this report.

2.0 An overview of the problem

It has been argued that the internal-combustion engine has revolutionised many aspects of transportation. For example, modern diesel-electric systems have replaced inefficient steam engines on the railways, and the development of petrol and diesel engines has provided basic mobility for ordinary people at relatively low capital cost. Goods vehicles have replaced commercial transportation of many commodities to such an extent that canals are used for leisure activities and little else. In many instances the convenience and speed of road transportation has led to its replacing rail freight traffic.

Hence in the industrialised world, there is an ever-expanding network of roads and motorways designed to increase the speed and improve the convenience with which it is possible to move goods and commute over large distances. But such is the volume of traffic now that traffic jams in cities are the norm, and it is not uncommon to find long tailbacks of vehicles on motorways or major trunk roads that often cannot cope with the volume of traffic using them. More importantly, the combustion of fossil fuels, however well they are refined, gives rise to exhaust emissions that are increasingly damaging the environment.

The motorcar can be used at any time and, although most are capable of carrying several passengers, the majority of motorcars being driven on the roads at any one time contain only the driver, who drives the car as a primary method of transportation. However, the number of private cars now in use and their relative affordability compared, for example, with 50 years ago means that in many areas, the personal automobile is the single greatest producer of harmful exhaust emissions.

The London smogs of the 1940s and 50s are well documented, but these were largely caused by heavy concentrations of particulates (soot) arising from domestic and industrial burning of coal mixing with fog and staying close to the earth’s surface because of temperature inversions. Many people died as a result of respiratory disease caused by these conditions. The London smog incident of 1952 lasted for five days and was a contributory factor in the deaths of more than 4000 people. Not until the passing of the Clean Air act of 1956 and its extension in the 1968 Clean Air act – together re-enacted in 1993 – to create smokeless zones and prohibit the combustion of coal, did the situation improve.

However, the relatively high personal wealth found in America meant that there was a much greater car population than Europe; many of these vehicles had large inefficient engines that consumed prodigious quantities of low-cost petrol and there was no attempt to curb the level of emissions they generated. States such as California increasingly found that on long, hot days the level of pollution from these emissions became intolerable as photochemical smog was created.

Photochemical smog requires four principal agents:
- bright sunlight
- nitrogen oxides
- hydrocarbons, and
- oxygen.

They react chemically to produce strong oxidants typified by ozone (O₃) and peroxyacetyl nitrate (PAN).
The generation of photochemical smog

It is these secondary pollutants that are damaging to plant life and lead to the formation of photochemical smog. PAN is the element responsible for the characteristic eye irritation. Additionally, there can be problems with evaporative emissions of fuel vapour from an engine while its fuel system is hot, and it is inevitable that some vapours will be released during refuelling.

Exhaust pollutants comprise:

- **Hydrocarbons** – the result of incomplete fuel combustion, they are a widespread, difficult air-pollution problem, are toxic and cause cancer.
- **Nitrogen oxides (NO\textsubscript{x})** – formed when nitrogen and oxygen in the air react at temperatures and pressures typical of an internal-combustion engine to form oxides of nitrogen, including NO\textsubscript{2}, NO\textsubscript{3} and NO\textsubscript{4}, known collectively as ‘NO\textsubscript{x}’. Like hydrocarbons they are a precursor to ozone formation and can contribute to acid rain.
- **Carbon monoxide** – a product of incomplete combustion, carbon monoxide forms when carbon in fuel is partially oxidised. It is highly toxic.
- **Carbon dioxide** – viewed by the US Environmental Protection Agency (EPA) as a ‘perfect’ combustion product because it does not directly impair human health, carbon dioxide is however a greenhouse gas that traps the earths’ heat and thereby contributes to global warming.

The addition of tetraethyl lead to petroleum blends, a standard practice since the second world war, gives rise to lead pollution of the air too, though this has been declining with the continuing replacement of leaded with unleaded fuel for road vehicles. The practice was formerly necessary to raise the octane number of gasoline-based fuel blends during the war when progressively more power was wanted from supercharged aircraft engines operating at high boost pressures. Tetraethyl lead has the additional advantage that the small amount of lead it deposits on exhaust-valve seats and stems provides a measure of lubrication, reducing wear of the valve seat and extending the life of the engine. Wartime petroleum blends were usually rated at an octane number of 85. (The octane number is a measure of temperature and pressure in an internal-combustion engine cylinder at which detonation will occur.) Detonation or premature ignition is deleterious to engine bearings because of the associated shock waves, and the higher the octane number, the greater the cylinder pressure measured either as a function of compression ratio for a naturally-aspirated engine, or boost pressure for an engine that is supercharged before detonation occurs. Higher cylinder pressures correlate with greater power output and improved engine efficiency. Improvements in refining and the addition of tetraethyl lead allowed octane numbers in the region of 100 to be achieved in aviation fuels, and ultimately this was increased to 150 octane but at the risk of spark-plug failure at low power settings.

3.0 Developments in engine, fuel and power-train technology

Similar improvements have occurred in automotive fuels, and during the 1950s and 60s most passenger-car engines were designed to run on 95-octane fuels; some sports cars, such as the E-type Jaguar and the Aston-Martin DB-series required 100-octane fuel to prevent detonation or pinking. These fuels resulted in a discharge of lead in the exhaust gases, and as the volume of traffic in cities started to increase there was increasing concern about the ingestion of lead by humans. Because the body is not able to excrete lead, it is a cumulative poison and can reach levels at which its toxic effects become apparent. This was for the reason that lead has been progressively removed from petroleum blends since the mid-1970s.

3.1 Engine design

Due to these developments, engines had to be designed using new materials that did not rely on the protective qualities offered by a leaded fuel, and it was a primary reason for research by the oil companies seeking a lead replacement that could be added to petrol to render it suitable for engines built before the
lead phase-out. More recently, the presence of sulphur in fuels has given cause for concern because burning it produces sulphur dioxide which, when mixed with water, forms sulphurous or sulphuric acid. Both are significant constituents of acid rain. The sulphur levels of most petroleum blends, as well as diesel fuels, have been reduced.

3.2 The control of emissions

Clearly, the removal of lead from petroleum blends necessitated reformulation, and by international agreement the car manufacturers decided to design engines around fuels having an octane number of 95 when measured under standardised conditions (95RON denotes 95-octane fuel as tested using the Research Octane Number method). However, in 1970 the US EPA began to dictate the levels of pollutants that were permissible in car exhausts. Initially this was achieved by the use of exhaust gas recirculation whereby a proportion of the vehicle exhaust was fed into the inlet manifold so that unburnt hydrocarbons could be fully burnt, and carbon monoxide oxidised to carbon dioxide as a consequence of an excess of inducted air consequent on running engines on a very lean fuel/air ratio. However, these measures resulted in a significant loss of engine driveability and caused problems such as flat spots, transmission snatch and a significant loss of power.

In 1975 the first generation of catalytic converters appeared, which dealt more efficiently with hydrocarbon and carbon-monoxide emissions, but because lead was found to poison the platinum catalyst, it was necessary to hasten the introduction of unleaded petrol. In fact, the lead content of petrol was progressively reduced as more vehicles appeared that had been fitted with catalytic converters during manufacture, so lead-free and ‘leaded’ petrol were offered alongside one another on garage forecourts for some time.

Catalytic converters gained in reliability and robustness to the extent that in 1980-81 many American manufacturers responded to higher emission limits by fitting vehicles with a ‘three-way’ catalyst that could convert carbon monoxide and hydrocarbons to carbon dioxide and water, and facilitate the reduction of NOx to elemental nitrogen and oxygen. All new petrol-fuelled cars sold in the UK since 1992 have a catalytic converter. Careful control of fuel-air ratios is needed to optimise the performance of these catalytic converters and hence fuel injection, controlled by an on-board computer and oxygen sensor, has replaced conventional carburettors, which, by comparison, now seem very crude.

A basic fuel-injection system and catalytic converter

Other factors such as ignition timing and the amount of fuel introduced into each cylinder will influence exhaust emissions, and for this reason modern engines are fitted with an engine control unit (ECU) which uses sensors to monitor engine speed, load, coolant temperature, ambient temperature, manifold depression, throttle position, air mass flow rates, cylinder detonation, etc. to enable ignition timing and fuel injection to be varied in real-time so that exhaust emissions are minimised. Additionally, the fuel system of most vehicles is recirculatory so that excess fuel not required for combustion is returned under positive pressure to the fuel tank. In this way the only time that evaporative losses can occur is when the tank is vented to air for refuelling purposes.

Limits for exhaust emissions will tighten in 2005 (see p.13) and this will require increasingly accurate mapping of engine parameters and more use ultimately of variable valve-timing systems.

Diesel engines are especially efficient and by offering a lower specific fuel consumption than vehicles fuelled by petroleum they are finding increasing application in private cars as fuel costs continue to rise. The excessive noise, smell and harshness traditionally associated with diesels is very much a thing of the past, and many diesel cars offer better driveability in terms of torque and acceleration than their petrol counterparts. Also, diesel cars had no need of exhaust emission controls in Europe until recently. However, this is changing rapidly with the introduction of more restrictive regulations.

Diesels emit relatively large amounts of nitrogen oxides (NOx) and particulates. However, catalytic converters
are difficult to apply to them because the exhaust temperature is low and engines tend to run lean (i.e. there is an excess of air in the combustion chamber). As a consequence, catalytic converters in the exhaust system of a diesel-powered vehicle can drop below their 'light-up' temperature during deceleration and idling when tested using the European driving cycle. Additionally, in a turbocharged engine the turbocharger will act as a heat sink, thus reducing downstream exhaust gas temperature by up to 150°C and exacerbating the difficulty of using a three-way catalyst. \(\text{NO}_x\) emissions from diesel engines are nevertheless decreasing as a consequence of research into combustion-chamber design, the use of high-pressure common-rail fuel injection, exhaust-gas recirculation and, more importantly, electronic fuel-injection systems mapped to meet engine demands in a similar manner to petrol engines, where engine speed, load, coolant temperature, ambient temperature, air mass flow rate, etc. are continuously monitored and used to regulate the amount and timing of fuel injection into each cylinder.

This increase in efficiency can have a significant effect on the emissions of particulates which, it has been estimated, can be up to 60-80% of the exhaust. Many of the exhaust gases are bound-up with these particulates, so that reduction automatically leads to a cleaner exhaust and it is for this reason that particulate traps or filters are incorporated into the exhaust systems of some diesel-powered vehicles.

Additionally, many diesel fuels contain some sulphur that will turn to sulphur dioxide/trioxide in the combustion process and this, when combined with water vapour, produces sulphuric acid, a major constituent of acid rain. It is for this reason that ultra low-sulphur diesel fuel has been introduced. Also, new technologies to reduce oxides of nitrogen in diesel exhaust appeared to work well when the exhaust gas contains very little sulphur because sulphurous products of combustion will poison a conventional catalyst and quickly reduce its efficiency. Therefore regulations have been proposed that will reduce the allowable amount of sulphur in diesel fuel from current levels of approximately 50 ppm found in 'ultra low sulphur' diesel. Some catalysts have almost zero tolerance to sulphur, however, so zero-sulphur diesel fuel is under consideration, though its production could be technologically challenging and expensive when it is considered that standard diesel fuel contains in the region of 500 ppm sulphur. Low-sulphur diesel fuels also tend to have a higher cetane number, providing easier starting, quicker warm-up and reduced white smoke. It is also low in polyaromatics - a considerable aid to the reduction of particulate emissions.

### 3.3 Power-train technology

Fuel economy and carbon-dioxide emissions are largely dependent on a driver’s ability to use a gearbox to optimise engine speed for any given vehicle speed and operating condition. However, because there are only a fixed number of ratios, it follows that much of a journey is spent with the engine operating away from its optimum condition. Attempting to overcome this problem by providing more ratios is expensive and offers only marginal savings because optimum operation is still very much dependent on the driver’s skill. Additionally, some manufacturers have opted for aluminium bodywork to reduce overall weight of a vehicle, and in some instances this has been found to be more productive than simply adding ratios to the transmission.

Many of the benefits of modern engine design and efforts to reduce exhaust pollution are negated if an inefficient transmission system is used or the driver has little feel for fuel economy. Hence there is a slow but steady increase in the acceptance of automatic transmissions that range from the conventional torque-converter principle to state-of-the-art gearboxes with continuously variable or infinitely variable ratios.

The current generation of four- and five-speed automatic transmissions for longitudinally-mounted engines uses planetary gear sets mated to a hydrodynamic torque converter that provides a start-up element. In America these dominate the mid-size and luxury car market, as well as many sports utility vehicles. However, they are not fuel efficient because of power losses in the torque converter. Recent years have seen the introduction of lock-up converter clutches which provide a direct drive at higher road speeds under cruising conditions, as well as electronic control, more ratios and integration with the engine management system. These offer much greater fuel efficiency and as a result the gap between an automatic and manual transmission has significantly narrowed. Additional benefits include better gear-change quality, simple manual override of the selected gear ratio, and the ability of some transmissions to adapt to driving conditions or driver behaviour.
In the late 1980s the five-speed automatic transmission was introduced, and this added to the attractiveness of automatic gearboxes. However, increased requirements for lower fuel consumption and emissions, combined with reduced weight and transmission size led to the development of six-speed units. Advantages include a 5-6% drop in fuel consumption, 5% better acceleration, 13% weight reduction, and increased reliability. An example is the ZF 6HP26 gearbox that can handle torque levels up to 60 Nm from eight- and twelve-cylinder engines.

Most current transverse engine installations make use of manual gearboxes, but where an automatic transmission is offered as an option it is usually a four-speed unit, although five-speed transmissions are being introduced by Volvo, Rover, Ford and Volkswagen. However, their design is based on existing four-speed technology and the lack of space means that gear sets and clutches are arranged on a countershaft which makes the unit expensive to produce and relatively heavy. Lower-torque applications where the gearbox is married to a four-cylinder engine, as in Honda’s Civic and Accord models, have designs similar to manual transmissions with the synchronesh units effectively replaced by wet clutches. One of most compact is the Mercedes A-class five-speed unit which can transmit up to 180 N.m of torque yet is contained within a length of 316 mm. Unfortunately, a demand for greater driving comfort and requirements for greater power and torque in this sector will make it necessary for vehicle manufacturers to offer automatic transmissions with more speeds; the employment of six-speed automatic transmissions having planetary gear clusters which are similar to those in standard driveline applications might be necessary to meet the need for reduced fuel consumption and emissions.

A more recent development in terms of basic transmission technology is the CVT or continuously variable transmission initially designed by Hub Van Doorne and first seen as the Variomatic fitted to all early DAF cars. Varying gear ratios are created by means of a variator with axial repositioning of a conically-shaped pair of discs between which a chain or belt transfers torque. By this means it is theoretically possible to match engine speed to any vehicle speed such that an engine operates at its optimum speed to achieve maximum power output or torque relative to fuel consumption and harmful exhaust emissions.

Basic principles of a continuously-variable transmission

Other forms of continuously variable transmission include hydrostatic systems in which variable-displacement hydraulic pumps supply fluid in response to demand from hydrostatic motors, and ratcheting systems where the stroke of a reciprocating motion connected to a freewheel results in unidirectional rotation. Hydrostatic systems have found use in the Hondamatic transmission, as well as many heavy off-road constructional vehicles, but it is probably true to say that most of the work has been carried out on friction continuously-variable transmissions, a good example of which is fitted to the new Mini built by BMW. This also contains Steptronic control, which enables the driver to choose between normal automatic mode, for easier driving in traffic, and a more sporty driving mode with a six-speed semi-automatic transmission. Although this unit is heavier than the mechanical transmission it replaces, it is still lighter than a conventional automatic transmission.

This CVT uses an oil-bath multi-disc coupling that is electronically controlled, and a fixed-length steel drive belt connects two double-core-shaped pulleys transmitting the drive output from the engine, essentially giving infinitely variable transmission ratios. A power-train controller continuously monitors belt position, engine speed, load, road speed, etc. so that the most appropriate ratio is provided. Additionally, sports mode offers greater acceleration as well as Steptronic gear changing, where six fixed ratios are provided by electronically limiting the unit to predefined gear change points that allow the engine to rev to 6000 rpm; gear changing is effected by means of switches fitted to the front and rear of the steering wheel spokes. Acceleration from rest is claimed to be especially smooth with CVT and Steptronic because the electronically controlled coupling does not transmit full power until an engine speed of 2000 rpm is reached;
instead the power produced is restricted but evenly transmitted to give smooth acceleration. Both operating modes – CVT and Steptronic – have kickdown and engine braking, as well as creep which can be very helpful in traffic driving. A similar form of transmission is fitted as an option in the MG ‘TF’, not to be confused with other five-speed automatic gear boxes often fitted to BMW or Range Rover vehicles, which are essentially conventional automatics with full manual override of the gear-change points plus the option of selecting a ‘sports’ mode.

However, CVT transmissions only provide positive ratios and it is accordingly necessary to provide a reverse gear and clutch (or a torque converter) if a vehicle is to be driven backwards. An elegant way of overcoming this limitation is the Infinitely Variable Transmission (IVT). Basically this can be in the form of a CVT that drives an epicyclic gear train. This will provide a positive and reverse drive from the sun, ring or planet gears. However, there has been considerable advancement on the concept of toroidal drives typified by the Torotrak, which provides a full range of ratios from reverse, through stationary to positive across a wide speed range. Unlike a CVT, there is no torque limitation. The ratio range is provided not by a system of gears as in a conventional automatic transmission but by a variator consisting of a set of discs and rollers; this is termed a ‘full toroidal’ variator.

The IVT is torque-controlled rather than ratio-controlled. Software determines the torque required at the road wheels and then requests torque from the transmission rather than setting a specific ratio. The engine can then be used to deliver power at its most efficient operating point, whereas in a conventional automatic transmission where the gear ratios are fixed, the engine only runs at its most efficient operating points for short periods of time. This optimisation of the power train results in a fuel economy in three ways:

1. The Torotrak IVT contains a planetary gear set, which enables the engine to be directly connected to the road wheels whilst the vehicle is stationary, i.e. a geared neutral. Hence there is no need for a separate starting device such as a torque converter, which can be inefficient.

2. The whole ratio spread of an IVT means the engine can run at a high overdrive – up to 74 mph per 1000 rpm.

3. An IVT does not have discrete ratio steps, and so can run under optimum conditions for fuel economy and emissions.\(^4\)

Input gears transmit power from the engine via a low-regime clutch to the planet gear in the epicyclic gear train, and it is these that provide the means by which a running engine can be connected to stationary road wheels without need for a slipping clutch or torque converter. Variators comprise two pairs of dished plates and rollers, and it is these that provide a continuous variation of ratio.

Torotrak claim that verified tests demonstrate an improvement in fuel economy in the region of 20% when compared with existing four-speed automatic transmissions and, unlike many technologies that provide significant fuel-economy improvements, there is no obvious downside for the driver of an IVT.

### 4.0 Hybrid systems

So far, this review has looked at the saving in fuel and commensurate emissions reduction attributable to careful fuel-system management, catalytic converters, diesel engines, particulate filters, mapped engine management systems, automatic transmissions and the development of infinitely-variable ratio gearboxes. These will certainly help in towns and cities, but there is perhaps more to be gained in this environment by using hybrid drivers.
Here the vehicle is fitted with an efficient internal-combustion engine that operates in conjunction with an electric motor. Basically, the engine charges batteries for the electric motor that reduces load on the engine, thus allowing it to run more efficiently, use less fuel and produce fewer emissions. Hybrid electric vehicles do not need to be recharged by connecting to an external source of electricity. Instead, they convert energy that is normally wasted during coasting and braking into electricity that is stored in a battery until needed by the electric motor. Petrol or alternative fuels stored in a conventional tank, plus regenerative braking, provide the energy needed.

There are many ways in which a hybrid drive system can be configured. For example, in the Honda Insight and Toyota Prius (2003 model) both the engine and electric motor are connected to the wheels by a common transmission. Intelligent power electronics decide when to use the motor and engine and when to store electricity in batteries for future use. More specifically, a 1.3 litre four-cylinder petrol engine in the Civic provides the primary power; when more is needed for overtaking, sustained uphill driving, etc. a 13-bhp electric motor augments what is available from the engine. This electric motor is positioned between the engine and transmission (which can be either a four-speed manual gearbox or CVT) and, because it is only used to assist the engine and not for primary power, both it and the battery pack are smaller than other hybrid drive systems. The batteries are automatically charged during braking and deceleration by using the electric motor as a generator, and to enhance fuel economy the engine management system temporarily shuts down three of the engine cylinders when coasting. Additionally, the engine shuts down completely when the car is stationary, although this feature is cancelled until the engine has reached its normal operating temperature or the air conditioning is switched on.

The second-generation Toyota Prius (2004 onwards) is somewhat more sophisticated. It can be driven using electric power only (the electric motor has an output of 67bhp), with the engine remaining off until depletion of battery charge dictates that it should be started. Transmission is a CVT auto and the petrol engine is a 1.5-litre DOHC 16-valve unit that develops 76 bhp.

This is the direction that several hybrid vehicles, including those operating primarily in towns and cities, such as buses, delivery vans will take. Electric power provides freedom from noise and exhaust fumes until such time as batteries need recharging or the vehicle is travelling in an urban area where the operation of an internal-combustion engine is more acceptable.

5.0 Fuel cells

Hybrid power is a move in the right direction when considering environmental issues, but ultimately a stage will be reached where the extraction of fossil fuels becomes prohibitively expensive as established reserves become depleted. For this reason, the development of fuel cells robust enough for operation in vehicles is attracting a lot of funding.

Evidence gained so far indicates that these will probably be based on hydrogen. Hydrogen can be burnt in a piston engine as a substitute for a hydrocarbon fuel and although there are no emissions of carbon dioxide (which is believed to cause global warming), there are still oxides of nitrogen in the exhaust because air must be introduced into the gas stream if productive power is to be created. However, fuel cells can be used to generate electricity from hydrogen and oxygen, and the only by-product is water.

One example of fuel cell technology is the proton exchange membrane, which has four basic elements:

- The anode conducts electrons that are released from hydrogen molecules so that they can be used in an external circuit. It has channels etched into it that disperse hydrogen over the catalyst surface.
• The cathode distributes oxygen to the surface of the catalyst and conducts electrons back from the external circuit to the catalyst where they combine with hydrogen ions and oxygen to form water.

• The electrolyte is the proton exchange membrane. It only conducts positively charged ions and blocks electrons.

• The catalyst is a special material that facilitates reactions between oxygen and hydrogen. It is usually fabricated from platinum power that is very thinly coated onto carbon paper or cloth, and is rough so that the maximum surface area is exposed.

Pressurised hydrogen enters the fuel cell on the anode side and is forced through the catalyst. When a hydrogen molecule comes into contact with platinum it splits into two hydrogen ions and two electrons. These electrons are conducted through the anode to an external circuit and then return to the cathode side of the fuel cell. At the same time, oxygen gas is forced through the catalyst where it forms oxygen atoms. Each of these atoms has a strong negative charge that attracts hydrogen ions through the membrane where they combine with an oxygen atom and two electrons from the external circuit to form a water molecule.

This reaction in a single fuel cell produces approximately 0.70 volts and therefore a fuel-cell stack must be constructed if a voltage suitable for powering a vehicle motor is to be generated. The system operates at 80°C which means that it does not require expensive containment structures, and it has been shown that a unit about the size of a small suitcase can provide sufficient power for a car. (see http://science.howstuffworks.com/fuel-cell2.htm)

Hydrogen is difficult to store and distribute, so it would be more convenient if fuel cells could use materials that are more readily available. This problem is addressed by a device known as a reformer that converts hydrocarbon or alcohol fuels into hydrogen that is then fed to a fuel cell. However, reformers generate heat and other gases apart from hydrogen that reduce fuel cell efficiency. Some of the more promising fuels are natural gas, propane and methanol. (see http://science.howstuffworks.com/fuel-cell3.htm)

If the fuel cell is powered by pure hydrogen it has the capability of 80% efficiency, whereas the conversion efficiency of methanol to hydrogen is approximately 30-40%. The conversion of electrical energy into mechanical work is accomplished by an inverter and electric motor which have a combined efficiency of 80%; therefore the overall efficiency of a methanol fuel cell vehicle (neglecting frictional losses) is about 26%.

It is anticipated that some fuel-cell powered cars that use a methanol-reformer system will be available in 2005, but the long-term aim of the major motor manufacturers such as Honda, Ford and GM is to market cars powered by hydrogen fuel cells. One experimental vehicle is the Honda FCX that has a 190 mile range on a tank of hydrogen and produces virtually no emissions. But as yet there are no bulk sources of hydrogen, so advancement of the technology will be reliant on the creation of a matching infrastructure.

6.0 Renewable energy resources

Renewable energy refers to power generated from a renewable source, ie when the energy is generated the fuel resource is naturally replenished and can either be managed so that it will last indefinitely, or the supply is so large that mankind cannot meaningfully deplete it. Unlike fossil fuels, most renewable energy sources do not release carbon dioxide or other air pollutants into the atmosphere.

Examples of renewable energy resources include:

• Wind power
• Solar power
• Biofuels
• Hydro-electric power
• Geothermal energy
• Tidal power
• Wave energy

Renewable energy resources currently provide about 3% of the UK's electricity supply, but it is targeted to rise to 20% by 2020 throughout the EU member states. Part of the reason for this is a significant cost penalty when compared with fossil fuels or nuclear power generation, but as renewable energy technology improves it is thought that the cost of these more sustainable forms of energy will become increasingly competitive.

Clearly, windpower, hydroelectric systems, geothermal energy and tidal or wave power are not applicable to vehicles as a primary power source, but biofuels offer
considerable promise when used in a compression-ignition-engine (diesel) engine. Rapeseed is a classic 'straight vegetable oil'; others include sunflower oil, olive oil and soya oil. All are mono alkyl esters derived from renewable biological resources and can be employed as a fuel with little or no engine modification. Additionally, they are biodegradable, non-toxic and essentially free of sulphur or aromatic compounds. Bio diesel has a higher lubricity than petroleum diesel and can therefore be blended with conventional diesel fuel without risk of wear to fuel pumps or injectors. It is also possible to filter old (ie used) cooking oil and run a diesel engine on it without detriment.

The advantages of biodiesel as a fuel include:

- Minimal soot emissions
- No carbon dioxide emissions, hence no effect on climate
- Energy independence
- No chemical processing required
- A wide range of plant oils can be used
- Low cost
- It is biodegradable
- If spilt in waterways, it is not harmful to fish
- Exhaust fumes are less offensive
- No special storage facilities needed

The production of biofuels is now supported by tax exemptions in Germany, Austria, Spain, France, Italy and Sweden. However, the adoption of biodiesel, which will almost certainly be used on an additive or extender to conventional low-sulphur diesel fuels, will require a substantial investment and the development of an appropriate infrastructure to promote farming the necessary crops, extracting the oil, and transporting it to blending plants.

Specifically, the biggest reason why biodiesel is classed as 'environmentally friendly' is that it does not contribute to nett carbon dioxide on the atmosphere. Additionally, it creates 30% less particulate emissions, 93% less hydrocarbons, 50% less carbon monoxide and up to 85% less poly-aromatic hydrocarbons (health-risk hydrocarbons associated with conventional diesel fuel). Also, changes in legislation will prevent used cooking oils (a major constituent of biodiesel) being utilised in the production of animal feeds to safeguard human and animal health. Biodiesel is therefore probably the most effective disposal route for waste cooking oils while offering a significant aid to the minimisation of atmospheric pollution from vehicles.

7.0 Market overview

7.1 Market size

The new car market in the UK is the second largest in Europe, employing over 827,000 people in 7 volume car manufacturers, 7 commercial vehicle providers and numerous total manufacture of components. The car industry has developed in the UK as many foreign car manufacturers found it attractive to invest in the UK as globalisation within the industry developed.

Global Industry Analysts Inc. suggests that there will be approximately 6,581 electric vehicles in the UK by 2005. The market is estimated to increase at an annual compound growth rate (CAGR) of 62.15% for the ten-year forecast period to 2010.

This trend is shown in the graph below, with all types of electric vehicles growing in terms of production. Hybrid Electric Vehicles (HEVs) are the segment of the market that are expected to grow the fastest in terms of volume, although Fuel Cell Electric Vehicles (FECVs) are the fastest growing product type, and will enjoy a CAGR of 115.15%. This is the equivalent of 8,672 units by 2010, compared to 45 units today.

Graph 1: UK Market for Electric Vehicles – A Current & Future Analysis Annual Sales (*) For the Years 2000 to 2010 in Units.
Note:  Product Types Independently Analysed – Battery
Powered Electric Vehicles (BPEVs)
Hybrid Electric Vehicles (HEVs)
Fuel Cell Electric Vehicles (FCEVs)

(*) Manufacturers Level
2004 & 2005 GIA Estimates
2006-2010 GIA Projections

Source:  Global Industry Analysts Inc.

Whilst it would appear that the market for electric vehicles and environmentally friendly transport is forecast to increase, there is minimal fiscal investment from the UK government to develop such alternative fuel technologies. According to the New Statesman, due to the lack of funding available, even the greenest fuels and cars have still less than 0.2% of their respective markets.

7.2 Market trends

The UK transport industry produced 86.0 million tonnes of carbon dioxide in 2002 compared with 88.3 million tonnes in 2000, and 54.5 million tonnes in 1990. Road transport greenhouse gas emissions accounts for 18% of the total, compared to only 14% in 1990.

The UK is keen to be viewed as a pioneer of cleaner renewable types of transport fuel, and would like bio-fuels to account for 0.3% of all road-fuel sales in 2005. The fuel currently receives 20 pence per litre discount from the normal fuel duty rate of 48.5 pence. One method of manufacturing bio-fuel is to process used cooking oil. At present in the UK, 100,000 tonnes of used cooking oil are collected each year. Rapeseed oil, another raw material for bio-fuel costs £373 per tonne, so used cooking oil, at £175 per tonne, is relatively cheap. Biodiesel is usually added at a ratio of 5% to conventional diesel fuel, but this blend is not readily available on UK forecourts. However, Tesco has taken the decision to increase the number of biodiesel pumps on its forecourts.

In order to increase consumer awareness of fuel emissions and efficiency, the government has announced that all new cars will have to provide details of their carbon dioxide emissions and fuel costs for travelling 12,000 miles. It is expected that this information will assist consumers when purchasing a car as to its efficiency, but also its impact on the environment. The grading system, which will take the form of grades A-F (as with white goods) will also take into account the amount of road tax that the car will have to pay based on the variable excise duty (VED). As would be expected, hybrid vehicles score well in such an exercise.

Hybrid vehicles are popular and fashionable America and Japan because they are thought to have a direct impact on controlling smog and pollutants, whilst also reducing fuel consumption.

However, it is not only the general consumer that needs to be educated as to the environmental advantages of greener cars. It is rare to see an environmentally friendly car on a company car list. However, in order to educate employees, the potential tax savings of a greener car should be highlighted, allowing them to make a purchasing decision based on their effect on the environment. Air pollution specialists at the Environment Agency have produced a list of the top 20 environmentally friendly models, details of which can be seen by using the link below:

www.fleetnewsnet.co.uk/news/view_article.asp?s=view_article&art_ID=31709

Ultimately, car manufacturers are driven by demand in local markets. For example, in America, much of the population likes its large, 4x4 cars, and there are no monetary issues with this style as petrol is relatively cheap. However, when this is compared with Europe, petrol prices are much greater, and therefore consumers are driven more by fuel efficiency. The next logical step is to fit hybrid technology in 4x4/SUD vehicles to gain the marketing advantages of both.

7.3 Market forecasts

According to Global Industry Analysts Inc., the car market in the UK can look forward to further enhancements in technology, incorporating a wider use of electronic management systems. A greater range of hybrid cars that use a combination of petrol and diesel, low emissions and Telematics will also be available.
Germany is the largest user of biodiesel in Europe. However, in Germany, the fuel is duty exempt. If further tax breaks could be introduced to the UK, then there could be an increased uptake of the fuel, that provides evidence to show how individuals want to take advantage of such technology. Mobile Emissions Today reports that a survey showed that 60% of drivers would take notice of the new scheme being introduced to assist motorists in understanding the efficiencies of motor vehicles when being purchased. This further substantiates that there is a market for more environmentally friendly modes of transport.

The UK sells approximately 2.5 million new cars every year. As a greater proportion of the cars bought are more environmentally friendly, this will gradually filter down into the second-hand market which will also be able to take advantage of greater fuel efficiencies and other savings. However, this market is still in its infancy and may take several years to mature.

One major concern is that as travel increases, any emissions savings will be hidden by the increase in volume. It is anticipated that fuel efficiencies in cars will contribute to decreasing emission levels, whilst in the aviation industry greater fuel efficiencies will be realised through replacement of fleets and further technology enhancements. The aviation industry is being targeted with a 50% decrease in carbon dioxide levels (based on 2000 levels) by 2020. By 2030, aviation emissions are estimated at accounting for 25% of the total UK contribution to global warming. It is suggested that passengers could be made more aware of how their choice of travel is effecting the environment by placing emissions levels on air tickets. Another alternative would be to charge passengers an ‘emissions charge’ instead of air passenger duty, thereby sending a clear message to both airlines and passengers.

For many car manufacturers the prohibitive factor in manufacturing more environmentally-friendly cars is competitive price pressure. It is estimated that the leading seven car manufacturers that are looking at fuel cell and hydrogen technologies spent approximately $2 billion in 2001 on research compared to total profits of $12 billion. General Motors has promised that it will be the first car manufacturer to produce a million fuel-cell vehicles. If all other car manufacturers made the same pledge, then it could spell the end for the combustion engine as we know it now. However, GM does not believe that significant numbers of fuel cell vehicles will be available until at least 2030.

### 7.4 Market drivers

In the UK, 80% of travel is done by car, and over 60% of freight is moved by road. This is a major reason for there to be greater emphasis on the development of more environmentally friendly vehicles. At present, heavy and large goods vehicles account for approximately 30% of road emissions. The car industry as a whole accounts for between 22% and 25% of global warming gases, is a major producer of toxic pollution and produces 10% of the world’s hazardous waste.

Aviation emissions are also to blame for the increased pollution, and appear to be growing at a faster rate. The aviation industry is subsidised by VAT exemption, or zero rating, on fuel, new aircraft and tickets. If a tax were levied on aviation fuel, this could alleviate the issue, but in order to do this, international agreement would need to be met, and this is unlikely. The alternative could be to include aviation emissions in the EU emissions trading system, which would have the effect of capping them, benefiting those aircraft makers and airlines that are considering the environment.

The market for more environmentally friendly vehicles is being driven in the UK predominantly though the great reduction in air quality that has been experienced over recent decades; also, as the country is becoming more dependent on imported oil, alternatives to petrol need to be sought.

On a global level, the Kyoto Agreement is also taking steps in the direction of reducing the pollution and emissions that are produced. Counties who have signed this agreement have said that they will aim to reduce emission levels by 5.2% of their 1990 levels by 2012. In 2002, Britain was performing exceedingly well with their emission levels, scoring at 14% below the 1990 levels.
7.5 Key players in environmentally friendly vehicles

7.5.1 Honda

Honda commenced their activities in the United States in 1979, and now employs over 25,000 people directly, not to mention the thousands of others that are employed indirectly through dealerships.

Honda has always been keen to ensure that their products are seen as environmentally friendly, and many of their vehicles are recognised for their low carbon dioxide levels and other pollutants. In doing so, Honda has improved the performance of electric vehicles. Honda received approval from the US government for their fuel cell in 2002, and this also gained approval in Japan.

Since they have been in operation, Honda has strived to ensure that vehicles that are developed using alternative sources of fuel have the same performance ratings as those using traditional technologies. In 1999 the company released their prototype vehicle using fuel cell technology. The product was finally launched in 2002, and was the first car in the world to gain approval for commercialisation in the US. Honda is keen to continue developing this technology further to enhance both performance and the impact on the environment. They are also very active with hybrid vehicles and have three models using this technology in the marketplace.

7.5.2 Toyota

In 1957, Toyota Motor Sales was established in the United States. Since then, the company has continued to grow and now employs over 35,000 people in North America.

Toyota has firm beliefs that environmentally friendly alternatives should be available for consumers, and it was one of the first car manufacturers to make hybrid vehicles, and launched the Prius in 1997. It is now the largest producer and retailer of hybrid vehicles in the world, and has developed the technology significantly over the years.

Toyota is keen that other vehicle manufacturers are able to benefit from such technology, and has stated that it is willing to make such technology available to them. That said, Toyota and Nissan have recently announced that they have an agreement in place for the long-term continuous transaction of hybrid systems. In the agreement, Toyota will provide Nissan with hybrid system components, and both companies will share information relating to the joint development of hybrid systems.

In March 2001, Toyota announced the FCHV-3 hybrid vehicle and, later that year, they announced the introduction of the FCHV-4, which had received the Minister of Land, infrastruture and Transport-certified licence plate which permits it to be used on public roads in Japan. However, Toyota is not just developing passenger vehicles; it has also announced the completion of the FCHV-BUS1. This is a bus for use in cities that uses high-pressure hydrogen fuel cell hybrid system. It was developed with Hino Motors Ltd. Such buses could be popular in cities, as they will reduce emissions and noise levels. Testing of the bus still needs to be completed.

7.5.3 Ford

Ford is continuously developing new technologies in order to limit damage to the environment. Their Sustainable Mobility Technologies department works to expand on the existing fuel cell vehicles. Ford has developed several models that are reliant on the fuel cell technology.

In 2004, Ford unveiled their Escape Hybrid SUV, which combines off-road functionality with the fuel economy and emissions benefits of a hybrid vehicle. Ford has developed the hybrid system to include advanced thermal management systems which will provide the battery with a longer life span. The vehicle is also thought to have improved acceleration. Low volume production of this car was due to commence towards the second half of 2004.

So impressed have they been with Fords technology that the US Post Office now uses Ford vehicles for their delivery fleet. Whilst the vehicles are more expensive than the conventional fuel alternatives, they also provide other savings such as saving on maintenance costs.

7.5.4 General Motors

General Motors (GM) is the world’s largest manufacturer of cars. The company was established in 1908 and now
employs approximately 324,000 people across the globe.

GM strives to reduce the emissions from their products whilst at the same time improve fuel economy. Their current objective it to be the leader in the industry for hydrogen fuel cell vehicles because they are so much more efficient and do not cause as much pollution; this is one of the main drivers for the organisation at the present time.

However, fuel cell vehicles are inherently more expensive than traditional cars and vehicles. In order to demonstrate the worth of such vehicles, GM has toured the United States to meet with public policy leaders and students to demonstrate the advantages.

As mentioned previously, GM is aiming to be the first car manufacturer to make over a million fuel cell vehicles.

8.0 Legislation

Motor vehicle emissions are regulated in the EU by directive 70/220/EEC (light vehicles) and 88/77EC (heavy vehicles), and amendments to these have been issued to reduce emission levels. Emissions are measurably falling because of this even though traffic volumes continue to rise, and implementation of the Auto-Oil programme should result in a noticeably improved air quality in cities. This focuses on emissions of carbon monoxide, volatile organic compounds, nitrogen oxides and particulates; stricter emission limits will be introduced for light vehicles from 2005 (Directive 98/69/EC), and heavy vehicles in 2005 and 2008 (Directive 1999/96/EC). This programme also covers durability such that manufacturers will be responsible for the emissions from light vehicles during the first five years or 80,000 km of their life provided the vehicle has been properly maintained.6

Additionally, legislation has been implemented on the use of on-board diagnostic systems that will inform owners if the emissions of a vehicle are too high; an instrument panel light will indicate that there is a need to repair the vehicle. It will also be necessary to reduce emissions during short trips, cold starting or city driving, when the efficiency of a catalytic converter is limited.

Directive 98/70 as amended by Directive 2003/17/EC contains the environmental fuel-quality specifications for petrol and diesel fuels. There are three distinct specifications. The first came into effect on 1 January 2000, and from 1 January 2002 all petrol sold in EU member states was unleaded.7 The second came into force on 1 January 2005 and sets limits for the sulphur content of petrol and diesel fuel (50 ppm), as well as the aromatics content of petrol (35% by volume). The third, as amended by Directive 203/17/EC, also came into force on 1 January 2005 and specifies a phased reduction of sulphur content from 50 ppm to 10 ppm.8

Noise is undoubtedly a problem for people living in the vicinity of an airport or military base where aircraft are operated. However, in recent years there have been concerns expressed about the level of exhaust products discharged into the atmosphere from an increasing volume of air transportation and the effects it might have on the environment, either directly by emissions of carbon dioxide, oxides of nitrogen (NOx), water vapour, unburnt hydrocarbons, soot and sulphate particulates or indirectly by a chemical chain reaction whereby ozone can be formed. The following changes potentially affect climate.

- Ozone, carbon dioxide and water vapour are greenhouse gases and their increase has a warming effect.
- Aerosols could have a cooling effect.
- Contrails formed due to the emission of particles and water vapour can increase cloud cover in the upper atmosphere. This may result in a cooling or heating effect depending on the size and optical depth of the ice crystals that form a contrail. It is believed that contrails have a net warming effect.
- There may be changes in non-contrail upper cloud level. Most condensation trails decay quite rapidly, but some continue to exist and are then not distinguishable to the human eye from natural cirrus clouds. The climate effect of changes in cirrus cloud cover are not clear.9

It has been estimated that in a single year, air travel releases 600 million tons of carbon dioxide into atmosphere. Also by 2050, it is anticipated that increased flights by jet aircraft will have an impact on global climate through the greater number of condensation trails they will produce according to a study completed in 1999 and reported in the Journal of Geophysical Research Letters. Additionally, a research team headed by Patrick Minnis of the NASA Langley
Research Centre in Hampton, Virginia has predicted that the generation of contrails will increase by a factor of six over the next 50 years and cause a warming of the atmosphere.

Engine manufacturers are working hard to reduce fuel consumption and improve efficiency. However, the fact remains that increased air transport will have an effect on atmospheric conditions that will probably be seen as global warming and an increased presence of greenhouse gasses.

9.0 Conclusion

Clearly there is much to be done if our basic freedom of mobility is not to further damage the environment. There is a finite life to the world’s resource of fossil fuels, and already some of it is becoming increasingly difficult to extract as once-prolific deposits (especially oil) become depleted. Transport is but part of the overall problem when compared with, say, the amount of carbon dioxide created by a coal or oil-fired power station; already much of this is collected and buried underground at very high pressure in naturally-porous rock where, in some instances, it can help with the extraction of oil or natural gas.

Our cities are suffering from the pollution caused by ever-growing traffic volumes, so either we restrict the use of cars in cities and rely on public transport, or take serious measures to reduce the levels of pollution caused by private vehicles. Maybe the answer is a compromise between both camps, but steps have to be taken to reduce vehicle emissions. Legislation is playing its part by forcing manufacturers to develop vehicles that are more fuel-efficient, as well as technologies to remove contaminants from exhaust gases. But there must be a limit to how far this route can provide a meaningful return on investment, and for this reason millions of dollars are being spent on the development of fuel cells that offer the promise of a clean, efficient energy source. Ultimately, this may be the only way forward.
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