

TRANSPORT

LOW CARBON VEHICLES DRIVING THE UK'S TRANSPORT REVOLUTION.

Institution of
**MECHANICAL
ENGINEERS**

Improving the world through engineering

The transport sector is responsible for 24% of all CO₂ emissions in the UK with the overwhelming majority produced by road vehicles. For the UK to achieve its 80% national reduction in CO₂ emissions by 2050, the transport sector will need to find radical ways to reduce its emission levels over the next 40 years.

This report provides an overview of the many alternative types of engine technology currently being developed. In addition, the report will outline a number of recommendations for Government and industry which need to be addressed if the consumer is to break its fossil fuel habit.

ENERGY

ENVIRONMENT

EDUCATION

TRANSPORT

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EXECUTIVE SUMMARY

DAWN OF A NEW TRANSPORT REVOLUTION

02_03

LIVING WITH OUR FOSSIL HABIT

Technological advances in Western society over the last 100 years have led to an exponential increase in energy use¹. In the main this has been provided by the burning of fossil fuels.

Fossil fuels are a convenient, readily accessible source of power with a high specific energy density that up to now has been available at an affordable cost. The downside is that in 2007 the UK released 560 million tonnes of carbon dioxide (2% of the global total) into the atmosphere due mainly to the burning of fossil fuels.

It is now generally accepted that increasing levels of CO₂ in the atmosphere, currently just under 390 parts per million (ppm), is driving global warming. Scientists believe that CO₂ atmospheric concentration must be limited to less than 450ppm to keep the planet habitable with an average temperature rise of less than 2°C.

However, with the world population steadily increasing, rapid industrialisation and a growing desire for higher standards of living in the developing countries, urgent worldwide action is required to control CO₂ emissions. If not, CO₂ atmospheric levels will pass the 450ppm threshold with profound consequences to the way the planet responds and our society develops in the future.

STEERING TOWARDS A CLEANER TRANSPORT SECTOR

The UK Government has introduced a number of legally binding targets that aim to reduce the nation's CO₂ emissions by at least 80% of 1990 levels by 2050. It is clear that all sectors of the nation's economy will need to take steps to help achieve these targets.

Currently, the UK's transport sector accounts for almost 24% of the nation's CO₂ emissions (or 135m tonnes in 2006). Of this total, road vehicles (cars, HGVs and LGVs) account for nearly 80%. With no viable alternatives to reduce our road usage (rail, sea and air are either near maximum capacity, impractical for passengers or high polluters), we need to examine alternative methods to power our road vehicles.

Technological solutions such as advanced traditional engines, hybrids, electric vehicles and biofuels will all play their part. But technology alone will not deliver all the answers and society will need to contribute by modifying the way in which we plan our travel requirements, if we are to succeed.

For the transport sector to make a significant impact on its CO₂ emissions, much more stringent targets will need to be set. The UK Government recently urged the European Union to set a vehicle fleet maximum of 100g/km CO₂ emissions by 2020, to follow up the current requirement of 130g/km by 2015. However, for any significant impact to be made on the 80% CO₂ reduction targets, a more substantial cut is required in the future. It is the view of the Institution that a target of 30g/km limit by 2050 is technically achievable and is needed to compensate for increasing fleet size and mileage.

POWERING THE FUTURE

In recent years the European Union and the UK Government have introduced targets for a wide range of industries to reduce their CO₂ emissions – the transport and power sectors being two notable contributors. However, much of Government thinking is not joined up. Various initiatives are totally unconnected. Some transfer a problem from one sector (or Government department) to another. For example, the BERR Scrappage Scheme has the potential to stimulate automotive sales. However, it presents Defra with an increased waste and disposal issue which will impact on their targets. Furthermore, with no emission limits for cars bought under the scheme, DfT CO₂ targets may well be affected.

With the recent announcements for a range of incentives to encourage the consumer to purchase electric or hybrid vehicles, as well as the introduction of a limited electric-car charging network, attention needs to be given to where the power to run the nation's new low carbon vehicle (LCV) fleet will come from. The benefits in electric-powered vehicles being charged by fossil fuel generated electricity are substantially reduced compared to using renewable energy sources.

SETTING THE EUROPEAN SCENE

The UK is well behind on exploiting the potential of electric vehicles. Apart from the Mayor of London expressing an interest in a scheme planned for Paris, it has all been talk so far with no formal strategy.

Denmark already has more than 10,000 electric vehicles on its roads and will have an extensive charging network by 2011. Using its wind energy to advantage, the electric vehicle batteries will also be used as energy storage for their National Grid. Renault-Nissan will market the vehicles at half the price of conventional cars and the Government will offer significant tax breaks.

Portugal plans to introduce a national electric vehicle charging network from 2011. Renault-Nissan will market electric vehicles at a similar price to comparable small conventional cars and will build a battery manufacturing plant in the country.

France; Paris has announced plans for an electric vehicle hire scheme similar to its Velib bike project with between 2,000 and 4,000 vehicles available.

Israel aims to end its dependence on oil by 2020 and will have an electric vehicle charging grid and battery exchange stations by 2010. Renault-Nissan will provide electric vehicle fleets for 19 major Israeli companies and the Government will offer significant tax breaks.

LIVING IN THE WORLD OF TOMORROW – UK RESEARCH AND DEVELOPMENT

Employing 850,000 people, with a turnover of £50 billion and producing some 1.5 million cars annually, the UK's automotive sector has a global reputation for research and development, design engineering and manufacturing².

The UK also has a world-class science and research base and a superb reputation for innovation. Two independent centres of excellence are already established, with CENEX addressing low carbon technologies and fuel cells and innoviTS researching intelligent transport systems.

Our strengths are clearly demonstrated by the success of our F1 engineers with many of their innovations transferable to the commercial market. There are many other examples of innovation such as Zytech, a company that not only manufactures complex electric powertrains for motorsport and the commercial market but also manufactures vehicles (the Smart Fortwo ED). Elektromotive is a successful UK based research, design and manufacturer of electric vehicle charging stations, and the low carbon Ford ECOnetic engine, manufactured in Dagenham, was designed and developed in the UK at Dunton Research and Engineering Centre.

The Government is already funding 16 innovative new projects through its £23m Low Carbon Vehicles Innovation Platform and has recently announced that this fund will be increased to £40m. However, is this enough?

The Institution believes that this level of funding falls well short of what is required if we are to achieve the Prime Minister's stated aim of making the UK Europe's capital for electric cars.

KEY FACTS

- The transport sector produces 24% of all UK CO₂ emissions.
- There is no viable alternative to move a significant proportion of road usage to rail, air or sea.
- Focus should be on reducing CO₂ emissions from road vehicles to 30g/km by 2050.
- The UK automotive sector employs 850,000 people, has a turnover of £50 billion and has a global reputation in research and development excellence.
- Government needs to incentivise industry and consumer to swap to low carbon vehicles.

RECOMMENDATIONS

In response to these challenges, the Institution of Mechanical Engineers has developed the following recommendations for Government, industry and other key stakeholders.

Demonstrate Political Leadership and Joined-up Thinking

- 1** IMechE believes that with transport emissions actually increasing with the size of the fleet and increased mileage, the current EU targets for average fleet emissions (95g/km by 2020) falls well short of what is actually required. We consider that a maximum of 30g/km by 2050 is both necessary and achievable.
- 2** That Government introduces a policy framework linking the increase use of low carbon vehicle technologies with an increased generation of electricity from renewable sources. Powering electric cars from fossil fuel power stations will only move the problem from one sector to another. Any increase in LCV numbers should be matched by revisions in the renewable energy targets.
- 3** That the Government continues to develop incentives for the consumer to adopt low carbon vehicles. In addition, the Institution believes that a long-term education campaign of LCV technology should be undertaken to inform the public of the range, value and feasibility of these technologies.
- 4** That the Government sets targets and a policy framework, in line with EU regulation, for an electric car charging network throughout the UK, including battery replacement stations. A standardisation of batteries would enable this network to have a viable, long-term future.

Industry Development and Funding

- 5** That all UK-based automotive manufacturers take full advantage of the EIB £1.3 billion loan scheme for the development of future LCV technologies.
- 6** Government should lead the nation by example as it is a major purchaser of vehicles. It should adopt a policy of purchasing low carbon vehicles where there are clear emission gains. Its purchasing power will help stimulate demand for these technologies and encourage further research and development.
- 7** That the Government looks to toughen the new £2,000 car scrappage scheme to apply only to the purchase of new vehicles with emissions below the fleet average targets. Furthermore, the Government's proposed £5,000 subsidies for electric or hybrid cars to be brought forward to 2010 to help stimulate the green motoring revolution.

INTRODUCTION

It is almost universally agreed that our climate is changing due to man-made emissions, mostly from fossil-fuel usage in power generation and transport. These climatic changes will have a profound effect on how our global society develops over the next few decades if efforts are not made to restrict CO₂ emissions. To date, treaties such as Kyoto have done little to mitigate CO₂ emissions, although they have increased the awareness of the issue.

In the UK, the present Government has undertaken to reduce our CO₂ emissions by 80% of 1990 levels (650Mt to 130Mt). This commitment will require all sectors of the economy to seek ways in which they can help reach this target.

The transport sector (road, rail, sea and air) contributed approximately 24% of all UK emissions (157Mt) with the vast majority of this coming from road transport (cars, LGVs and HGVs). With our transport system heavily skewed to road, there is little capacity to migrate passengers or freight to alternative modes without considerable financial investment and changes in personal mobility habits.

As alternative transport systems (rail, air and sea) currently seem unlikely to be able to cope with any sizeable migration, without significant investment, it is becoming increasingly necessary to look at the source of the emission problem – the internal combustion engine powered by fossil fuel. Although this technology has significantly improved its efficiency and emission levels over the last few decades, the continuing global growth in car ownership (China, India and Brazil being prime examples) means that any emission efficiencies are being outstripped by the actual increase in numbers of cars worldwide.

A secondary, but no less important, factor is the growing scarcity of oil. Oil has powered the economic development of the world over the last century. However, the readily available sources of oil are beginning to run out. Although it is estimated that at current consumption rates, proven oil reserves could still be available for another few decades, their extraction will become increasingly difficult and therefore more expensive. Finally, the industrial growth of nations such as China and India further increase demand for oil, creating price fluctuations between \$20 and \$160 per barrel in recent years. This has had a profound effect on the cost of running cars and HGVs, and has encouraged industry and Government to seek alternatives for the future.

How can the transport industry do its bit to help us keep below the 450ppm emissions target, and how low can the fleet average emissions be driven down? The Institution believes that with an increasing vehicle fleet size and mileage, the current EU maximum emissions requirement falls well short of what is actually required.

In Europe the car 'fleet average' is about 160g/km. EU regulations require this to reduce to a maximum of 130g/km by 2015. In a speech to the World Wildlife Fund in November 2007, the UK Prime Minister pledged to lobby for a vehicle fleet emission level of 100g/km by 2020³. These are laudable targets that are continually being revised downwards but it would be more realistic if they also covered fleet size or total mileage, both of which are actually increasing.

Reducing vehicle emissions is not new. Since the 1970s, legislation has achieved more than 98% reduction in NOx and particulates¹⁸. While CO₂ is not a noxious gas, it is still a pollutant, and in recent years it has become the focus of legislation. Our current understanding of chemistry does not allow CO₂ to be treated by catalysts so it falls to the industry to make the energy conversion system more efficient and to use fuels that produce less CO₂.

To make a real difference, it is estimated that the worldwide fleet average needs to move towards being 80% below the current average. Based on an EU fleet average of 160g/km, this represents 32g/km⁴.

The Institution firmly believes that the technology exists to make 30g/km by 2050 an achievable target and that anything higher will not guarantee that emission targets from road transport will be met. Even then we need to take further measures to limit fleet size and fleet mileage to ensure the overall 80% reduction is achieved. Setting a 30g/km target today will allow sufficient time for industry to plan and develop the technologies, thereby helping to secure a successful future for the UK automotive industry.

The Technology Strategy Board, a Government agency, is providing £100 million to promote and implement new concepts and ideas in vehicle and powertrains to reduce overall emissions. But is this enough?

In the 2006 Stern report, it was recommended that the UK spend 1% of GDP on actions to tackle climate change. In June 2008, Lord Stern updated this estimate saying; "To get below 500ppm... would cost around 2% of GDP." This would be approximately £28 billion per year for the UK. (In April 2009, the budget allocated just over £1 billion for all 'green' initiatives.)

Following the Stern report, Prof Julia King, Vice Chancellor Aston University, published a report for the Treasury in March 2008 to illustrate the technologies likely to feature in the reduction of emissions from cars.

King recommended the use of plug-in hybrids that used electricity generated overnight. However unless the electricity is generated from a low-carbon source, the reduction in total CO₂ emissions would not be significant⁵.

KEY FACTS

- EU fleet average target is 130g/km by 2015
- UK Government wants a target of 100g/km by 2020
- IMechE recommends 30g/km by 2050 to counter increased fleet size and mileage.

SOURCES OF ENERGY: HOW GREEN IS GREEN?

Pollution from transport is made up of both tailpipe emissions and the original production of the energy supply. The phrase that reflects this full life cycle of emissions is 'well to wheel'. Some of the solutions offering the best potential to reduce overall emissions will depend upon our national energy supply coming from more renewable sources, and with less reliance on fossil fuels.

Until recently the UK, with its North Sea reserves, was self-sufficient in its energy requirements. However as these reserves have dwindled, we have become a net of importer of energy. In 2007 the percentage of UK primary energy and hence CO₂ emissions originating from major sources was⁶:

Natural gas	39%	92%	Fossil fuels
Oil	36%		
Coal	17%		
Nuclear power	6%	Hydro, wave, wind etc	Nil/Low CO ₂
Renewables	2%		

Oil resources are finite and one estimate even predicts that accessible reserves will be exhausted within 42 years⁷. Perversely this may make a significant contribution to increasing emissions as a switch to coal will allow fossil fuel use well into the next century⁸.

Comparing the density of energy from alternative sources, John Baxter, Group Director for Engineering at BP, in his 2007 Presidential Address to the Institution of Mechanical Engineers, showed that in terms of emissions, the combined renewable portion of our national energy sources produces only 1/400 the CO₂ of fossil fuels. However, to replace the UK's fossil fuel power stations with low-energy density renewable alternatives would be very costly, eg. it would require tens of thousands of wind turbines⁹ and there has to be sufficient wind when the energy is required. To make full use of wind power innovative solutions such as conversion to hydrogen or hydro-gradient schemes are required to store the energy when wind speeds are high. In addition, we most likely need to have 'smart' systems to reduce demand from non-critical systems eg. battery chargers for electric vehicles at peak times.

Finally, although there are benefits of centrally generating energy to power the transport sector's low carbon vehicles, we need to ensure that we have not moved the problem from one sector to another. Powering electric cars from fossil-fuel sources does contribute to overall CO₂ reductions, but clearly not as much as if the electricity were entirely from a renewable source. In addition, the action of millions of people plugging in their vehicles at the end of the day would undoubtedly cause issues for the National Grid unless some controlled charging systems were put in place.

The Government needs to demonstrate joined-up thinking in its development of a strategy for LCV technology and the potential UK energy gap. The Institution recommends that the DfT and DECC work in unison to match the growth in non-fossil vehicles, with an increase in the percentage of renewable sources of energy or nuclear power, thereby helping to power the next generation of LCV from low-emission energy sources.

TECHNOLOGY SOLUTIONS

It is generally accepted that not one single technology will immediately solve all emission issues in the transport sector. This is because many technologies are either still in their infancy, do not provide sufficient emission reductions, or have high cost implications. It is more likely that a combination of technologies will, over time, come together to develop the vehicles of the future.

The Institution is concerned that Government and media often promote individual technologies or solutions which are impractical for the requirements of freight or passenger mobility.

It is therefore our preference to use the term Low-Carbon Vehicles (LCV), which is an all-embracing term for many different technologies. In addition, we believe the public are confused by the many 'green' options reported, and therefore Government should undertake a long-term promotional campaign with industry to explain why we are undertaking research into LCV technologies and what options and technologies are being explored. It is our belief that an educated public will make more informed decisions on future new car/HGV purchasing.

In addition, the Government should take a courageous step and adopt a low carbon standard in procurement of its own vehicles. The public sector is a huge user of vehicles. Introducing standards favouring LCVs where appropriate will not only reduce the carbon emissions, but also set an example to consumers and businesses. If LCVs are to become the norm, then public perception must change. Government must lead the way and use LCVs as much as possible, and set ultra low emission limits for the remainder of the fleet.

The following section outlines some of the alternative technologies being explored.

Technology Solutions

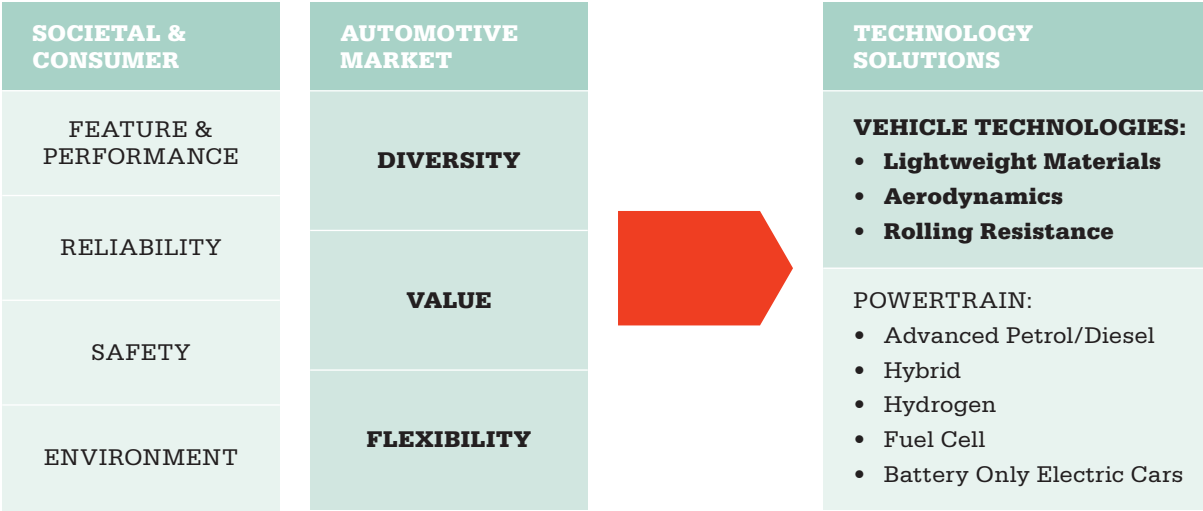


Figure 1

VEHICLE LIGHT-WEIGHTING

With the use of higher specific strength materials, including aluminium and composites, vehicle body weights can be reduced by between 25% and 40%. Combining this with smaller vehicles, optimised aerodynamics, improved lubricants and low rolling resistance tyres will help tremendously, however, there is only so much that can be done within the constraints of the number of seats, comfort and safety. Second cars could be targeted to offer less accommodation while maintaining key customer needs and reduced emissions.

ADVANCED PETROL AND DIESEL

The internal combustion (IC) engine is a mature and reliable technology that has been refined over 100 years. The best diesel IC engines now have an overall efficiency of 40% to 45% compared to only 30% 15 years ago. This is despite an 8% fuel economy penalty incurred by the introduction of sophisticated after-treatment systems for NOx and particulates. There has been a convergence of petrol and diesel IC performance and it is likely that they will remain the main vehicle powertrain for at least another 30 years¹⁰.

In the short term, IC petrol engines will be able to deliver an overall fleet average close to 100g/km. A diesel engine operating with very high mean effective pressure and excess air will offer further improvement in specific fuel consumption, particularly if used as the prime mover in a series hybrid. Diesel engines could plateau between 80g/km and 90g/km and the challenge will be to make further reductions in the NOx and particulate emissions. This technology should be useful for at least another 40 years¹⁰. Future actions to down-size engines and add turbo and supercharging, will increase overall efficiency and, when coupled with smaller, lighter vehicles and the use of biofuels, cars could be close to 70g/km by 2020.

Adding hybrids to this mix should help to reduce the fleet average, but these vehicles may not suit every driving mode. While they will provide CO₂ savings during urban duty cycles, they will add to the task if used extensively for long-distance driving. It may well be that series hybrids with improved IC engines using second-generation biofuels are probably the optimum solution⁴.

HYBRIDS

There are a number of different hybrids, each offering advantages depending on the duty cycle, fuel usage and energy storage systems. In general these benefit from being used in an urban stop/start environment where range (<60km) is not the prime concern.

Stop/Start

In its simplest form, a stop/start system is where the IC engine stops when the wheels are not turning, and starts automatically when the accelerator is pressed. Many manufacturers already offer this optional technology and more will in the future. It provides a simple affordable technology which can offer between 7%–10% reduced emissions and is particularly beneficial in the urban environment.

Series Electric/Hydraulic/Flywheel

In a series electric/hydraulic/flywheel hybrid there is no direct link between the IC engine and the road wheels. The engine drives a generator/pump/flywheel and the energy is stored until required by the driveline. The vehicle uses a small lightweight IC engine tuned for efficiency. Series hybrid buses and delivery vehicles that store hydraulic energy and claim up to 40% reduction in CO₂ emissions are currently under trial¹¹.

General Motors has announced its first electric series hybrid – the Volt, a family saloon with a 1.4-litre petrol engine. The battery range alone is about 64km, and when launched in 2011, is expected to cost about \$32,000 (£22,000).

Parallel Hybrids

The market leader using this technology is the Toyota Prius, which can be run as either a series or parallel hybrid and has a range of about 4km on battery power alone and cannot be recharged overnight. The latest version includes a plug-in feature and a higher capacity battery allowing a range of about 60km before the engine has to start. With the addition of overnight charging the car offers improved fuel economy, but with an approximate 15% increase in cost. However, as with all these technologies they can be considered to have low emissions only if the energy is supplied from a low-carbon source. While experts cannot foresee a wholesale migration to hybrids in the near future, they are providing a technology 'bridge' to what may be the next dominant powertrain. An analysis by JD Powers predicted hybrids will represent <3% of the world sales volume by 2010¹².

Hybrid technology with its energy storage capability will also support the use of regenerative braking.

BATTERY-ONLY ELECTRIC CARS

In 1904 there were more battery vehicles in Detroit than IC engines, and it was the development of effective clutches, transmissions and starters that led to their decline. In 2008 Tesla launched an electric sports car that uses 6,800 Li-ion laptop batteries. It is an expensive vehicle at £89,000 (over three times the price of an equivalent petrol sports car) and is over 500kg heavier. The Tesla has a range of 220 miles per charge and a battery life of five years/100,000 miles, but at such a price it is unlikely to become a serious high-volume vehicle. In December 2008 there was a drop in overall car sales of 30% and a 50% drop in sales of electric cars in the UK, mainly due to cost difference¹³.

A world expert on Li-ion batteries, Dr Yet-Ming Chiang, MIT Advanced Battery Group, maintains that at the moment batteries are too heavy, too big and expensive. Wider issues such as recycling batteries also remain to be tackled, due to the chemicals present. The supply of lithium and cobalt will need to be increased, and the mining and refining process is also very energy-intensive¹⁴.

Regarding the recharging of the batteries, there are already tried and tested examples of plug in charging infrastructures, but these systems require significant investment. Such systems will need to be in operation before large uptake is likely. Battery charging times can also be quite long with five to six hours needed for a full recharge. While this may be acceptable for most consumers, there could be capacity implications if everyone charged overnight. An alternative is to have a network of battery-changing stations. Standardising batteries and connections would not be difficult and re-charging could be co-ordinated with the energy companies. There is also the potential for the charging stations, with their banks of charged batteries, to act as suppliers to the National Grid when demand is high.

As a wide network already exists for the distribution of petrol and diesel, we would encourage companies to undertake feasibility studies to see if these stations could become petrol/charging stations in the short to medium term. In addition and where appropriate, renewable sources of energy should be installed to recharge batteries if possible. Many motorway service sites would have the necessary space.

Battery technology is still in its infancy and most countries are engaged in research. The potential reward for being first to market with breakthrough technology is enormous. The USA has recently announced a breakthrough in molecular technology that claims a full recharge in five minutes – on a par with the time taken to re-fuel a car.

FUEL CELLS

The Honda Clarity was launched in 2008 as a consumer trial. The vehicle uses a hydrogen fuel cell and Honda will produce 200 units over next three years, which will be leased to customers in Japan and the USA. Fuel will be provided from a 'home generator station'. Here the hydrogen is derived from the domestic supply of natural gas/electricity. Despite this it is claimed that overall emissions will be 30% lower than a conventional vehicle¹⁰. Using hydrogen fuel cells in volume applications has significant issues, not least of which is the setting-up of a retail fuel network. But as Honda's President said in June 2008 at the launch of the Clarity, "When petrol cars were invented there were no filling stations".

While these vehicles are just the start of an emerging technology, there is a long way to go before they will be able to offer a high-volume, economic and affordable alternative. Fuel cells can be powered by a variety of fuels, but there are continuing difficulties with the storage and transport, particularly with hydrogen, due to its atomic weight (the atoms are so small that the gas leaks away through most materials, including metals).



WHILST EXPERTS CANNOT FORSEE A WHOLESALE MIGRATION TO HYBRIDS IN THE NEAR FUTURE THEY ARE PROVIDING A TECHNOLOGY 'BRIDGE' TO WHAT MAY BE THE NEXT DOMINANT POWERTRAIN.

HYDROGEN

Depending on its source, using hydrogen as a fuel could potentially give zero emissions, and there is no reason why it cannot be burned in low-cost IC engines. A paper presented at a recent SMMT seminar, concluded that a hydrogen-powered Ford Transit with an IC engine gave exactly the same overall total efficiency as the 22% predicted for the lifetime of a fuel cell¹⁵. However, after ten years of development the technology still only just matches the efficiency of an IC engine but with a major on-cost. Currently the biggest concern is providing low-cost, efficient hydrogen storage and distribution in either its gaseous or liquid form.

The 2007 Energy White Paper considers a move towards a hydrogen economy. But hydrogen has a low-energy density by volume, compared to petrol¹⁶, and in liquid form has to be stored at -253°C, providing storage and transportation challenges. Additional energy is required to liquefy hydrogen and to keep it in that state. Hydrogen does not occur naturally and its production requires significant energy.

A recent IC H₂ demonstrator needed a 140-litre tank for a 200km range. The equivalent range for this volume of petrol would have been more than 750km. The tank stored hydrogen at 700 bar and cost about £25,000. Even in mass production it is difficult to foresee that the cost could be halved. On this basis alone it will be hard for the technology to compete with conventional vehicles.

A successful 27-month trial of H₂-fuelled London buses needed 45 tonnes of liquid H₂ to be imported from Holland. It was made from reformed natural gas and only 18 tonnes was used to propel the buses, the remainder evaporating during storage to keep the fuel in liquid form¹⁷.

Powertrain Technology – Timeline

Based on D-Class car @ 8.5km/l (~200g/km)

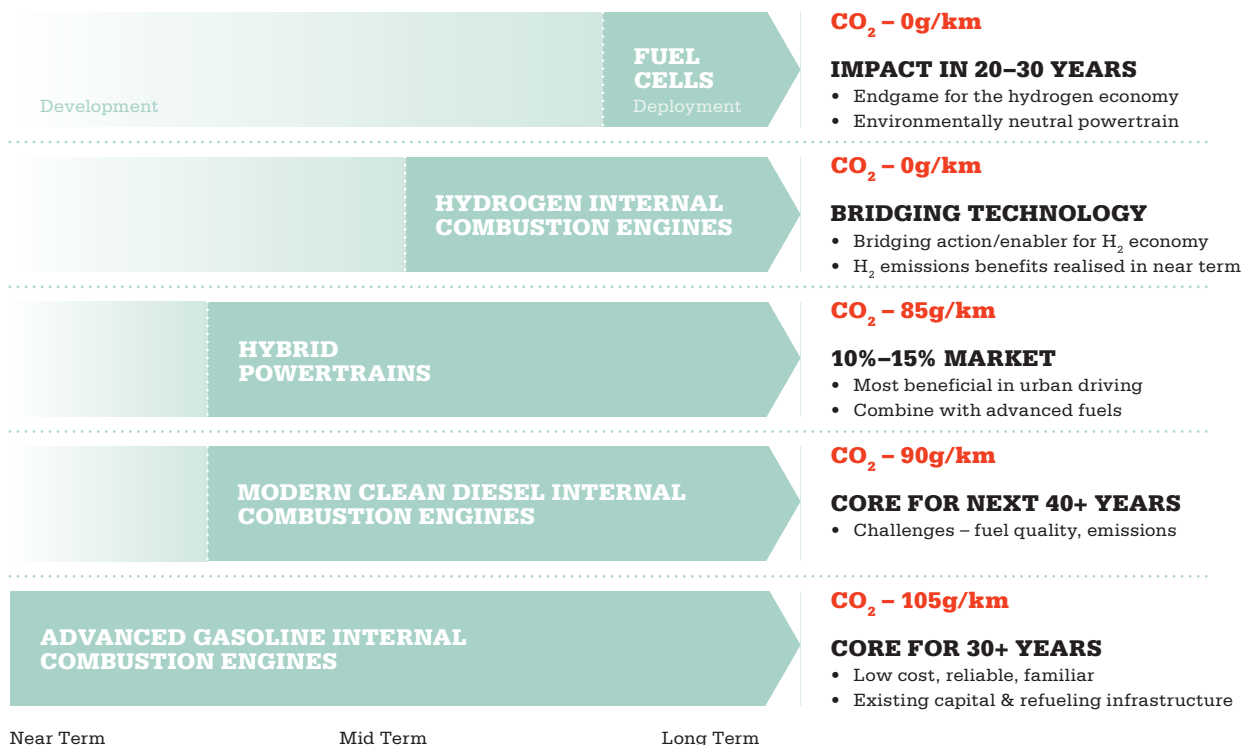


Figure 2

COMPARISONS OF COST AND CO₂ EMISSIONS

In **Figure 3**, effectiveness of the available IC technologies are compared. The base line is the current petrol fuel injection system (PFI), where petrol is injected directly onto the back of the inlet valve of each cylinder. The chart provides a measure of cost versus CO₂ reduction and gives a visual roadmap for all the known technologies for future powertrains. Today there are cost-effective technologies available that will provide a 20%–25% reduction in CO₂ emissions. Significantly, short to mid-term actions to increase the supply of 'second generation' biofuels coupled with 'matched hybrids' would offer a big step in further reducing total CO₂ emissions. This would offset some of the potential problems in 2050, when oil is predicted to become scarce. Today a bio-ethanol powered family car can deliver a 50% reduction in CO₂ emissions and would cost about £15,000 in the UK, representing an incremental cost of <£300. In Sweden, 45% of new cars run on E85 (85% ethanol 15% petrol needed for cold start). The fuel is made from waste wood chippings from the Swedish timber industry. This virtuous scheme, backed by the Swedish Government, demonstrates the benefit of official intervention and 'joined-up thinking'.

The industry may actually be turning full circle, the first Model T ran on bio-ethanol before the oil industry became established.

The key issue with full hybrids is that for optimum performance, they need to be matched to customer usage patterns. The manufacturers claim that under test conditions they deliver a 40% reduction in CO₂, but in the real world they have achieved almost the same overall emissions as a diesel equivalent but at a significantly higher cost (+£2000 on a £14,000 car)¹⁸. Some Prius customers were delighted with free access to congestion charging zones, but others found it difficult to achieve published economy, possibly due to their usage profile. However Toyota will have gained invaluable information on the production and manufacture of hybrids along with a greener image. The introduction of a 'plug in' version with higher-capacity batteries should help resolve the issues, especially if it is restricted to urban use and short journeys to make full use of the enhanced range in electric drive. Using biofuel would further reduce CO₂ emissions.

As discussed earlier, hydrogen powered vehicles will require a large and complex storage tank that significantly increases the cost and weight, while reducing the available space for the user. In the long term, adding a fuel cell further increases the cost. At this stage it is not clear if or when the technology will be able to deliver an affordable package for volume production.

IC Technology Comparisons

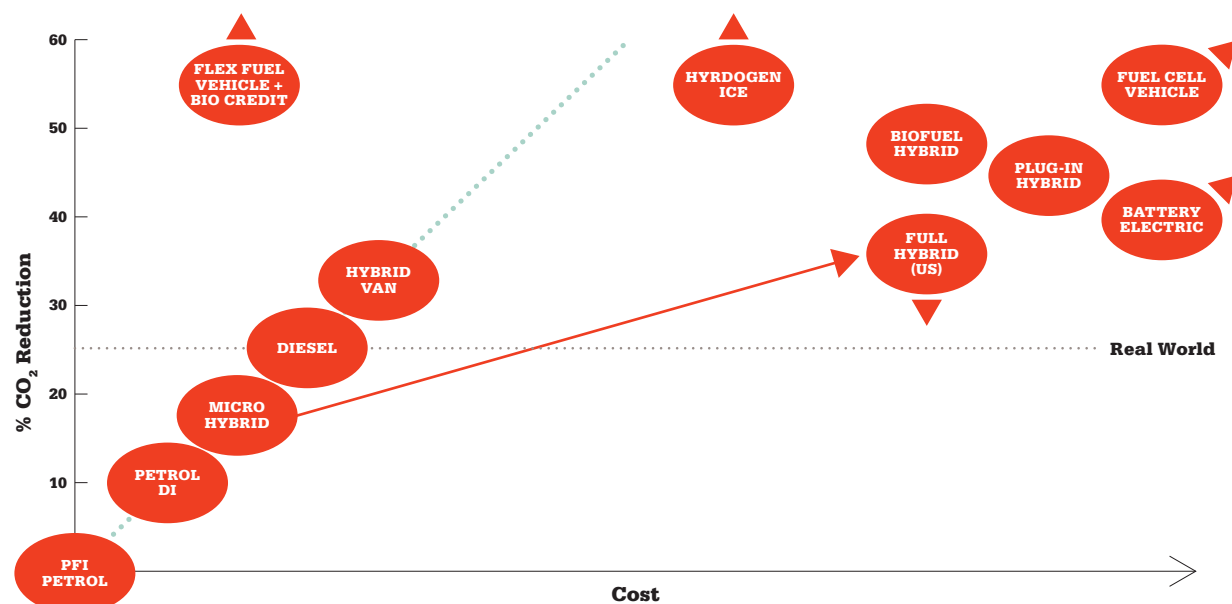


Figure 3: (data courtesy FMC Ltd)



Technologies Timeline



Known technology but needs optimisation for volume production

Requires breakthrough technology to for optimal performance

Figure 4

FUTURE OF THE TRANSPORT REVOLUTION

There is not a single dominant technology or solution to the problem. We must focus instead on the range of technologies that can meet our 30g/km 'well to wheel' target. The most promising existing technologies are the use of biofuels (which are particularly effective in reducing emissions if supplied from waste biomass), and electricity if produced from renewable sources.

Fuel cell technology will not be mature enough to realistically contribute to emissions reduction within the next 20 years. There are still major technical hurdles to be overcome. A fuel cell vehicle would currently cost more than £250,000, but the main issue would be the size and cost of the fuel tank.

Affordable technology will be the key driver. If the industry is to get to below even 70g/km, we need all the technologies available and utilised in the next generation of vehicles. To achieve less than 30g/km by 2050, will certainly depend upon the availability of renewable energy supplies to support the manufacture of alternative fuels.

In the short term we are likely to be driving stop/start hybrid vehicles with the increased use of biofuels to minimise the CO₂ emissions. Part of the challenge will be demonstrating to consumers the advantage of low CO₂ vehicles, so that it becomes a major part of the purchasing decision, just as NCAP did for safety ten years ago¹⁹.

So where do we need to get to? We have a Government target of 100g/km by 2020, but that is not enough. We have to strive for larger reductions, particularly as we do not know how much natural CO₂ absorption will increase as levels in the atmosphere rise. If we take into account population growth, and 50% more people worldwide seeking affordable and comfortable personal transport, we need to get to an overall level of <30g/km; an 80% reduction in car CO₂ emissions from 1990. It will be possible only if the chosen powertrain technology makes appropriate use of biofuels and our national energy supply comes from more renewable sources or nuclear.

Transport reductions in CO₂ represent tough technical challenges, but they are not impossible. It is probably the most exciting challenge that the current and next generation of engineers and scientists have ever faced and the rewards for success will be enormous.

Significant quantities of low cost energy stored from renewable sources will be required, if we are to provide affordable transport technology after 2050, delivering CO₂ emissions of <30g/km. Affordability will be critical. A clue to the future comes from a remark made by Sir David King, former Government Chief Scientist "There is enough sunlight falling on the planet every hour to meet man's energy needs for a year."

At the moment we don't know how to economically capture and convert solar power into the energy forms that we need. Basic scientific research is needed to achieve breakthroughs in solar power capture/conversion, and the recovery of waste low-grade heat and its conversion to useful power. There is still a lot to be done to improve the overall efficiencies of our traditional industries. People must look outside their normal boundaries and ask how they can contribute.

Climate change will not be solved by politicians, but they can set targets and pass enabling legislation. Certainly things will not happen unless engineers and technologists are given the support they require. In the next 50 years the responsibility of providing solutions to the CO₂ challenge will fall on the world's engineers and scientists. It will be an exciting time for engineers and it will present great business opportunities for those who develop the key technologies.

- ¹ 'World Consumption of Primary Energy by Energy Type and Selected Country Groups, 1980–2004' (XLS). Energy Information Administration, U.S. Department of Energy. 31 July 2006. www.eia.doe.gov/pub/international/iealf/table18.xls.
- ² Ultra-low carbon vehicles in the UK, HM Government April 2009
- ³ www.whatgreencar.com/caremissions.php
- ⁴ Engineering the Future in a Changing Climate. Prof. R Folkson, May 2008
- ⁵ www.parliament.uk/documents/upload/postpn268.pdf
- ⁶ www.makingthemodernworld.org.uk/learning_modules/geography/06.TU.06/?section=6
- ⁷ DTI National Statistics. www.berr.gov.uk/files/file11250.pdf
- ⁸ www.peakoil.net/IWOOD2002/ppt/UpsalaRB.doc
- ⁹ <http://physics.ius.edu/~kyle/E/Reserves.html>. Energy Information Admin, Int Energy Annula 2001 DOE/EIA-0219(2001)
- ¹⁰ Automobile Engineer 10 December 2008
- ¹¹ www.epa.gov/region09/air/hydraulic-hybrid/
- ¹² www.greencarcongress.com/2005/02/jd_power_hybrid.html
- ¹³ Autocar January 2009
- ¹⁴ <http://scitizen.com/stories/Future-Energies>
- ²⁹ <http://automobiles.honda.com/fcx-clarity/home-energy-station.aspx>
- ¹⁵ http://en.wikipedia.org/wiki/Energy_density#True_energy_densities
- ¹⁶ www.bristlingbadger.blogspot.com/2008/07/londons-hydrogen-buses.
- ¹⁷ CUTE, A Hydrogen Fuel Cell Bus Project in Europe 2001-2006: Vision, Teamwork and Technology. Detailed Summary of Achievements, May 2006, p.24
- ¹⁸ www.telegraph.co.uk/earth/environment/climatechange/5109251/Trees-are-growing-faster-and-could-buy-time-to-halt-global-warming (html and The Times 21 September 2007).
- ¹⁹ www.thenakedscientists.com/forum/index.php?topic=17714.0



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