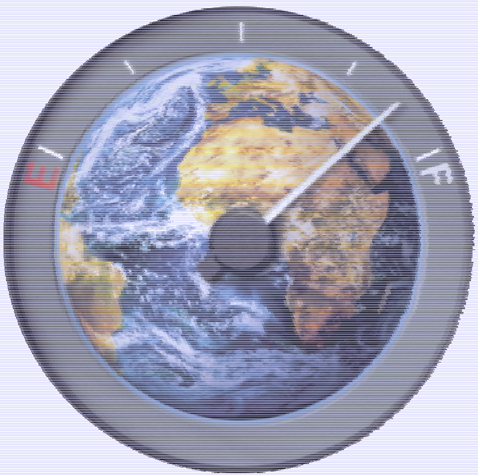
TOWARDS A SHARED VISION

FUTURE FUELS AND SUSTAINABLE MOBILITY



SMMT FUTURE FUELS STRATEGY GROUP

MARCH 2002

THE FUTURE FUELS REPORT

Annex

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Executive Summary

Background

Over the past two decades, the motor industry has progressively risen to the challenge of reducing the air quality impact of its products. However, there is now general recognition that climate change is a threat to the earth's ecological balance in which the CO_2 resulting from the combustion of fossil fuels in vehicles is a factor. The industry has already started to address this additional challenge of reducing the climate change impacts of road transport. The European car industry has reduced its new car average CO_2 emissions by 8.6%[1] over the 1995-2000 period and the European motor industry's voluntary commitment will deliver a 25% reduction in CO_2 emissions from new cars by 2008 from 1995 levels. Many developments based on conventional fossil fuels and technologies are currently being pursued and will continue to contribute to these objectives.

Together, all these actions are expected to achieve a major improvement in air quality and a stabilising of CO_2 emissions through to around 2010.

The motor industry is also developing the use of alternative fuels and breakthrough vehicle technologies that have the potential to reduce further the climate change impact of the use of motor vehicles. The SMMT Future Fuels Strategy Group has considered the options for a future fuels strategy for the timeframe of the next 2 decades and beyond in the light of the simultaneous need for CO_2 reductions, emission control, and security of energy supply. The committee's report primarily addresses the 'Climate Change' and 'Air Quality' challenges posed as part of the Government's 'Powering Future Vehicles' consultation. It does not specifically address the challenges of 'Noise' and 'Resource Use'.

Constraints & Assumptions:

1. The Kyoto agreement requires a 12.5% reduction in greenhouse gases by 2012.
2. The U.K. domestic goal is for a 20% reduction in CO_2 by 2010.
3. The ACEA voluntary commitment will achieve the target of 140g/km fleet European average CO_2 for cars (equivalent to a 25% reduction) by 2008[1]. There is an expectation that the industry will subsequently be under further pressure to make significant additional reduction in CO_2
4. The Royal Commission on Environmental Pollution has suggested that a 60% reduction in Greenhouse Gases is required by 2050, and it is assumed that this requirement will be adopted by Government and hence will influence vehicle requirements.
5. Air quality will continue to improve as result of the replacement of older vehicles - giving reductions in vehicle CO, HC, NO_x and PM – until about 2020, when it is

[1] Monitoring of ACEA Commitment on CO_2 Emission Reduction from Passenger Cars. Joint report of ACEA and the Commission services: year 2000 report of progress in delivering the commitment; 28 June 2001

predicted that the growth in vehicle mileage will start to offset the effects of cleaner vehicles.

6. In the next 20 years the current rate of utilisation and cost of fossil fuels will be under considerable policy scrutiny by European member states as they tackle climate change
7. Road transport is responsible for 22% of UK greenhouse gas emissions –the third biggest.

The Challenge:

The challenge for the motor industry is thus to make major reductions in CO_2 whilst also meeting low emissions including noise

Solutions

There are measures that the industry can take on reducing rolling resistance, downsizing (subject to customer acceptance), aerodynamics, intelligent systems . [Note that aftertreatment systems result in the conversion of HC and CO to CO_2]

However, the contribution to CO_2 reduction of these measures is finite. It should also be noted that whilst smaller lighter cars should result in CO_2 reduction, the same is not true for commercial vehicles. This would result in a greater number of vehicles and hence an increase in CO_2. One solution here would therefore need to be to improve and utilise allowed payload.

There are also fuel and vehicle systems [detailed in the FFSG report] that can progressively provide partial and interim solutions.

Near term developments will include a mixture of improved conventional fuels / technologies, alternative fuels and hybrid technologies*. Ultimately the challenges require the introduction of low or near-zero carbon fuels.* All fossil and vegetable-based fuels contain carbon.
Different factors will govern the timing and rate of introduction for commercial vehicles.

Discussion:

The road transport sector has a very wide variety of applications, from local personal transport to international haulage operations. The new technical solutions are not likely to be universally applicable to all sectors of road transport either in terms of function or timing.

Clearly, approaches leading to a wide range of alternative fuels or technologies in the market will inevitably dilute the resources that should be utilised to develop the best alternatives. Therefore, policy initiatives must bear in mind the need to avoid excessive diversity of fuel options. This is particularly true for alternative fuels that require major infrastructure or major vehicle investment.

However the motor industry considers that a step change in CO_2 reduction can only be achieved by a move away from carbon-based fuels. Such a move may also alleviate energy security concerns. Hydrogen is regarded as the fuel that offers the greatest potential as the long-term solution to the objectives identified for many vehicle sectors. Fuel cell technology offers an efficient means of converting hydrogen's chemical energy to mechanical work, though conventional spark-ignition engine technology can also be used.

However, hydrogen must eventually be produced by sustainable means that minimise CO_2 emissions if it is realise its potential for reducing greenhouse gas emissions from vehicles, otherwise, the case for hydrogen as the future fuel is undermined.

It must be emphasised that the introduction of radical new fuel and vehicle technologies to support environmental objectives will not of itself generate customer acceptance and demand. Government action is required as a stimulus.

The nature of government action and policy initiatives is critical to success.

Previous actions by authorities in various countries to address road transport air quality issues have had very mixed results. The key to success is an open, constructive partnership between government and the various industry sectors, coupled with a long term vision and consistent strategy implementation.

In respect of the change to hydrogen fuel cell technologies, this would represent a dislocation of power-train technology and investment after over one hundred years of evolution of the IC engine fuelled by petrol and diesel. Massive changes also would be needed to the fuel refining and distribution infrastructure to move to hydrogen.

The investment required to facilitate these levels of change could not be justified to service the UK market alone and, therefore, the UK government must ensure a common approach with other EU Member States to define appropriate EU policy for implementation EU wide.

This report provides discussion of the general considerations in developing a Future Fuel Strategy for road transport. It also discusses the key issues that confront the motor industry in accommodating the changes implied by the possible strategic options

Conclusions

The automotive industry has always sought that governments should set fuel standards which are neutral to the technology that might be developed and, more latterly as alternative fuels have been placed on the market, also set standards neutral of any fuel or energy carrier. However, assuming that collectively EU Governments can justify the significant reductions in CO_2 envisaged to eliminate the global temperature changes being discussed, then fundamental step changes in technology and fuels seem to be required.

Whilst the FFSG report identifies and discusses many fuels options, it is the view of SMMT members that under these constraints only hydrogen offers the potential of an environmentally sustainable transport fuel in the long term as it is the ONLY carbon free fuel that is potentially available to us.

Addressing the motor vehicle's contribution to climate change by moving to a low carbon fuel requires a technology step shift for both fuel and vehicle technology. This will involve massive new product and fuel infrastructure investment. The scale and complexity of this task is such that the industries involved will need to operate in partnership with Government and with clear common objectives. This new approach is required to implement a shift in product technology aimed at providing societal benefits rather than enhanced functionality for the consumer, and which will result in increased product and fuel costs.

However, for hydrogen to realise its potential for reducing greenhouse gas emissions from vehicles, or any other source, it must eventually be produced by sustainable means that minimise production CO_2 emissions. Otherwise, the case for hydrogen as the future fuel is undermined. A European study is currently under way to determine the well to wheel life cycle assessment of fuels in a European context, which will be vital to the acceptance of any new fuel.

Recommendations

In the short to medium term it is expected that the parc will be dominated by vehicles using developments of existing fuels and technologies including hybrids.
It is important that Industry, Government, the Energy Supply Industry and society co-operate in the development of a long term strategic vision of future road transport fuels, and achieve common goals. This vision needs to encompass local air quality improvement, reducing impact on global warming, and energy security.

Experience already gained in the UK's experiments with alternative fuels have shown the problems with trying to handle a variety of different fuels, from various aspects such as quality, consistency, availability, safety, public awareness and knowledge, planning consents, long term product planning, research & development costs and even taxation policy.

To meet society's needs of affordable sustainability, we need to concentrate on meeting the global warming targets with the lowest number of fuels toi make sure that the final solution(s) is (are) financially sustainable for all concerned – vehicle manufacturers, fuel suppliers and users.

The FFSG report includes a number of recommendations on specific fuels.

The key recommendations are that:

- Government should take note that the motor industry considers that hydrogen is the fuel that offers the greatest long term potential for reducing motor vehicle CO_2 emission

- Government should engage constructively with the motor, the fuel supply and other key industries affected to develop the optimum strategy to support a shared vision.

- Policy approaches need to consider the influence of product life cycle on technology introduction, including the time needed for product development and validation, a phased introduction to gain customer acceptance and a sufficient period of stability to achieve acceptable commercial viability.

- The UK government needs to work in co-ordination with the EU and ECE to ensure a co-ordinated long term European approach to future fuel strategy

- UK Government should establish a Hydrogen Task Force to develop and manage a minimum 10 year hydrogen introduction strategy

- Government and industry should participate in the development of international standards.

- Fiscal policies need to be developed and implemented with long term commitment to
  - ❖ make the use of hydrogen attractive to consumers,
  - ❖ provide capital purchase assistance and
  - ❖ promote infrastructure development

Further important recommendations concerning different aspects of strategic options are provided in the body of the report.

This paper is the first step by the motor industry to engage with government in the process of developing a shared vision of future fuels. It is appropriate at this stage for government to join with industry in developing this vision to achieve a common goal.

MAIN REPORT

1 Introduction

Towards a shared vision of sustainable mobility

Automotive Industry Strategy For Future Fuels

Purpose

This document was compiled to establish a common point of view amongst the UK motor manufacturers regarding future fuels and technologies. It provides a substantive contribution to the UK government consultative exercise on future fuels with the objective of ensuring the successful implementation of any Future Fuel Strategy.

Scope

This document considers the development of vehicle fuel and power-train technology solutions that could reduce emissions, particularly CO_2 and therefore contribute to sustainable mobility for road vehicles. It examines the conditions needed to move progressively from the use of current conventional fuels and technologies towards a sustainable scenario during the 21st century. It includes consideration of both passenger and goods vehicle sectors. It does not consider alternative measures to limit these emissions such as traffic management, alternative forms of transport, etc. There is also no attempt made to assess the cost/benefits of reducing the emissions from road transport compared to the other sources that emit these gases to the atmosphere.

Introduction

The motor industry has a history of successfully responding to society's mobility needs. In addition to addressing consumer desires for convenient, safe, comfortable and efficient personal transport and cost-effective commercial vehicles, industry has also embraced the wider societal requirement of minimising the environmental impact of road transport.

By 2010, the quality of tail pipe emissions for new vehicles will be such that any further regulated reduction will have a minimal environmental impact. By then, sufficient part of the existing vehicle fleet will have been replaced by newer, less polluting vehicles, to ensure a significant reduction of total emissions from present levels. Any future technological developments in this area will be driven by different factors; namely possible climate change by reducing emissions of known greenhouse gases, dependence on non European oil reserves and the long term need for sustainable renewable energy sources.

In global, regional and national policy development, the major environmental challenge facing the automotive industry now and looking set to remain so in years to come is that of CO_2. This challenge is being partially addressed by efforts and

[2] Monitoring of ACEA Commitment on CO_2 Emission Reduction from Passenger Cars. Joint report of ACEA and the Commission services: year 2000 report of progress in delivering the commitment; 28 June 2001

commitments of the automotive industry to reduce fuel consumption. However, to achieve a step change in CO_2 levels, new technologies and fuels will be required. Central to this challenge is the future development of road transport fuels.

Rapid technological developments are leading to a diversification in road transport fuel options. It is important that Industry, Government and Society reach agreement on the ultimate fuels of the future and all parties work to achieve the timely introduction of this goal.

Aims of Future Fuels Strategy Group

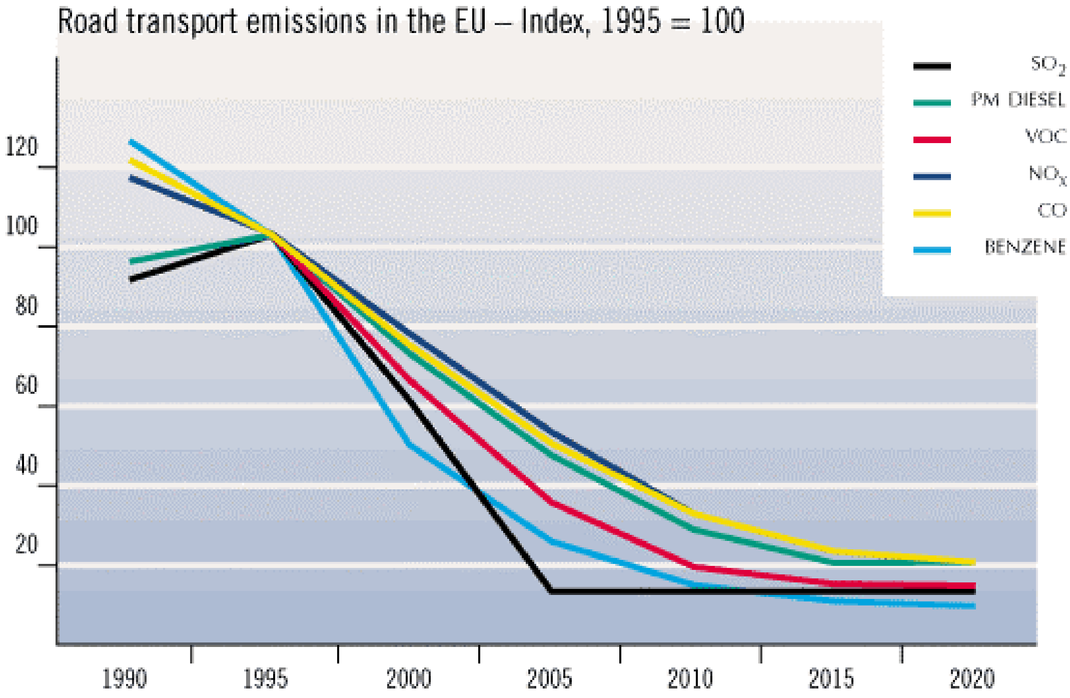
Early in 2001 SMMT member companies established a Strategy Group to consider the long-term future of automotive fuels. The Group has the following objectives:

- *Identify the major motor vehicle fuel alternatives*
- *Identify the advantages and disadvantages of the different fuels*
- *Identify the best long term fuel or fuels*
- *Propose an introduction strategy for long term fuels - 2020 and beyond*
- *Map possible routes towards the long term strategy*
- *Identify measures to encourage the development of cleaner conventional technologies.*
- *Identify measures to encourage the development of low carbon vehicles and fuels infrastructure.*
- *Identify measures to encourage mainstream markets for clean fuel vehicles.*
- *Identify the government support required*
- *Establish how these measures could be exploited to establish the UK as a leader in the development of clean fuel vehicle technology*
- *Provide a body of expertise in preparation for the consultation process*
- *Develop an SMMT position paper*

2 Drivers for change

Current liquid and gaseous fuels for road vehicles provide a highly effective method of mobile energy supply. They have certain common characteristics:
- the physics and chemistry of their use in an internal combustion engine result in the production of small amounts of material which includes carbon monoxide [CO], hydrocarbons [HC], oxides of nitrogen [NO_x] and particulate matter [PM], all of which are of concern for urban air quality
- they contain carbon so their combustion for energy production results in the output of CO_2 with consequent contribution to global warming; and
- their supply is dependant on a finite resource which is only partially a national or EU reserve

To ensure sustainable mobility in the future it is necessary to address all three of these issues. The efforts made by the motor industry to reduce vehicle emissions by design of the induction and combustion system, by use of after-treatment and by an understanding of the influences of fuel composition have yielded major reductions in emissions. The recent Auto-Oil 2 projections for the UK demonstrate that by 2010 significant reductions of major pollutants will have been achieved as the current vehicle parc is gradually replaced by newer, lower polluting vehicles.



Source: Auto Oil II Transport Base Case / August 1999

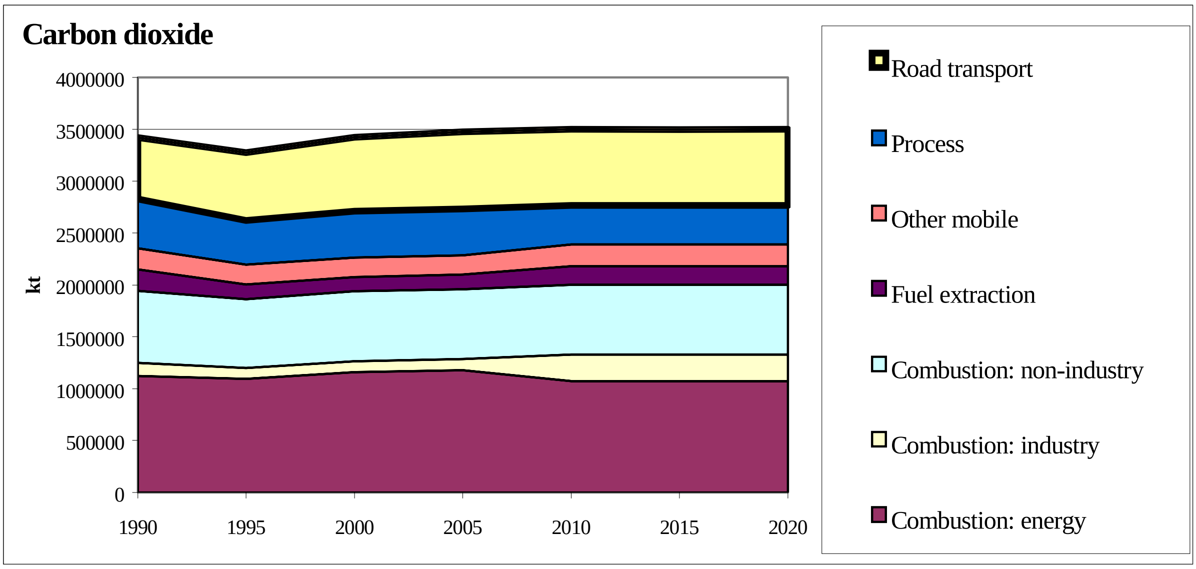
Future fuels and power-trains must continue these improvements, whilst continuing to provide the standards of safety, comfort and driveability that the user has come to expect.

Similarly improvements in combustion efficiency and the lessening of frictional losses are assisting in the reduction of energy consumption and hence CO_2 emissions.

In heavy-duty vehicles fuel efficiency is a major driving force for business resulting in a continual assessment of fuel (and hence CO_2) saving opportunities.

Regarding cars, the European motor industry has already cut its new car average CO_2 emissions by 8.6%[4] over the 1995-2000 period and the improvement is continuing. This is despite the fact that a range of factors such as car safety improvements, other automotive regulations, and customer-driven vehicle utility enhancement resulted in average car mass and engine power increasing by 7.9% and 14.3% respectively over the same period.

Reduction In CO_2 – source Auto Oil II



It must be recognised that there are potential conflicts in meeting these requirements and in many instances a compromise is necessary to provide a balanced environmental improvement.

The introduction of petrol engine catalytic converters demonstrated such a compromise. The catalyst has been highly effective in reducing the 'air quality' emissions of CO, HC and NO_x. However, the need to operate these devices close to the stoichiometric air-fuel ratio initially inhibited opportunities to utilise fuel efficient 'lean burn' technologies for petrol engines and the opportunity for better fuel economy was thus delayed.

Future fuels scenarios may well introduce new areas of compromise, particularly between the three driving forces. It is not sufficient to examine the vehicle in isolation. The environmental effects of alternative fuels and power plants must be considered on a 'well-to-wheel' basis both in terms of their air quality emissions and of the CO_2 and other Greenhouse Gases resulting from their production and use.

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[4] Monitoring of ACEA Commitment on CO_2 Emission Reduction from Passenger Cars. Joint report of ACEA and the Commission services: year 2000 report of progress in delivering the commitment; 28 June 2001

However, the ultimate goal of zero ‘air quality’ emissions together with zero global warming gases cannot be realised in the short to medium term.

It will require that the options be considered in the light of the compromise between short-term effectiveness in these goals and the long-term potential for achieving them. It may be necessary to compromise on some aspects to permit progress on vehicle, fuel and infrastructure growth.

3 Limitations to/Restraints on Change

A key factor that will prevent the step change from today’s petrol and diesel fuelled vehicle technologies to alternatives with lower environmental impact, is market competitiveness. IC Spark-ignition and compression-ignition engines have benefited from many years of evolution and though very sophisticated devices, they have become highly cost effective in design, manufacture and use. The cost of fuel refining and distribution is also relatively low. These are a result of large-scale investment in manufacturing and infrastructure, made over many decades. Economies of scale associated with high production volumes also contribute to the low cost.

As has been demonstrated with LPG, new fuel technologies will not initially be able to compete with established products without some stimulus to overcome market resistance resulting from additional costs to the consumer, lack of familiarity with the technology and lack of widespread infrastructure. (see Appendix) It is expected that some vehicle technologies, once significant market penetration has been achieved, would compete commercially on the market. As an example, the fuel cell would be an attractive product on reaching volume production supported by an extensive fuel supply infrastructure. However, in the early introductory period it would cost significantly more to produce than current technology, the fuel processing and supply costs would be high, and the availability of fuel limited.

Inertia to change within industry relates to managing current investment and minimising the risk associated with future investment. The vehicle manufacturing and fuel supply industries are highly capital intensive and involve medium to long term product planning and investment decisions. These investments of course carry risk. However risks are calculated and contained based on a company’s knowledge of the market and customer requirements and the potential of future products. Typically motor industry investment patterns are based upon an evolutionary approach to their product with innovative enhancements.

The major risks associated with investment in new vehicle power train technology requiring alternative fuels are:

- technology introduced before full maturity with respect to engineering development resulting in customer dissatisfaction
- investment stranded due to lack of customer acceptance resulting from
    - fuel unavailability

    - high product cost
    - inadequate performance characteristics / functionality
    - wariness of new technology, affecting residual values
- investment stranded due to new invention or radical improvement in conventional technology
- fragmentation of the market by government incentivisation of multiple technological paths
- visibility and stability of future government policy
- Insurmountable technological obstacles encountered

Addressing the motor vehicle contribution to climate change by moving to a low carbon fuel requires a technology step shift for both fuel and vehicle technology. This will involve massive new product and fuel infrastructure investment. The scale and complexity of this task is such that the industries involved will need to operate in partnership with Government and with clear common objectives. This new approach is required in order to implement a shift in product technology aimed at providing societal benefits rather than enhanced functionality for the consumer; this product technology will most likely result in increased product cost.

In practice the consumer's first consideration is the lifetime cost of the vehicle, including purchase price, residual value and cost of fuel. Each of these elements can be significantly influenced by Government policy. The customer takes for granted easy access to vehicle refuelling points and hence Government policy and planning also needs to address issues such as local authority building regulations, fuel standards, infrastructure development and long-term availability.

In order to maintain UK industry's manufacturing and technology base, government should consider a supportive national strategy (within a common European policy) to assist technology development and initial product introduction as a factor in creating market conditions that will enable acceptance of the higher cost of the alternative technologies and fuels.

4 Technologies:- current and future

The range of technologies for the future covers both power-train units and fuels. Internal combustion engines have been in a state of continuous and accelerating improvement since their invention over 100 years ago. The emphasis of future developments in both spark ignition and compression ignition engines will be to continue to minimise their emissions and fuel consumption while improving mechanical efficiency and power output. This is likely to ensure their continued use well into the future.

There are numerous options for fuels for internal combustion engines, each of which are discussed in more detail in the Annex to this report. Not all of these fuels will prove viable. Some may be usable in conventional unmodified engines, but most will require some degree of modification to the engine or its fuel delivery system, including elements such as changes to fuel system materials to ensure compatibility; changes to injector capacities to cope with different densities and energy contents; requirements for fuel composition sensors and specific engine 'tunes'. One of the greatest barriers to future development is that a 'scatter gun' approach leading to a wide range of alternative fuels in the market magnifies the development requirements for engine /vehicle manufacturers, reduces commonality and hence increases piece costs and inevitably dilutes the resources that should be utilised to develop the best alternatives, yet might service only a niche market with minimal opportunity to recoup development and production costs.

Current areas for conventional engine development include the following:

Direct injection spark ignition can permit ultra-lean operation (for low CO_2) under appropriate conditions and which require near-zero sulphur petrol,

Homogeneous charge compression ignition is at an early stage of development. It offers the potential for low NO_x and particulate emissions but it may well require a fuel that has significantly different properties from either current petrol or diesel.

H**ydrogen fuelled spark ignition** offers the potential to operate on a carbon free and potentially renewable fuel. Hydrogen internal combustion vehicles will require a hydrogen fuel infrastructure, although the first introduction vehicles are likely to be bi-fuel, also capable of running on petrol and hence easing the problem of starting-up the refuelling infrastructure.

Flexibly fuelled vehicles have been developed capable of using any mixture of two fuels in a single tank. In the case of bio-ethanol/gasoline the benefits associated with ethanol are supplemented by the convenience and flexibility of gasoline.

Bi-fuelled vehicles can run on either of two fuels, each needing its own tank. This facility is helpful when there is limited infrastructure supply of a new fuel. Typically the fuels would be petrol/LPG or petrol/CNG. The alternative fuel offers reduced CO_2 emissions and reductions in NOx compared with petrol but optimisation of the alternative fuel combustion has been compromised by the bi-fuel requirement.

Mixed fuel (sometimes known as **dual-fuel**) vehicles are being developed that run on a carefully controlled and continuously varied blend of two fuels each contained in its own tank. Diesel/natural gas is an example.

Petrol and diesel **hybrid electric vehicles (HEVs)** can combine the benefits of an electric vehicle with the range and flexibility of conventional internal combustion engined vehicles. These will include various methods of utilising the combination of an IC engine and electrical energy (e.g. charge depleting , charge sustaining, series, parallel – see Annex.). Further, the hybrid concept can also be extended to cover other technology combinations. Depending on the development of battery and fuel cell technologies, they could serve as an interim solution prior to the widespread use of a fuel cell vehicle. This technology is likely to be used in the short to medium term for cars, light vans and buses and possibly in the medium to long term in heavy commercial vehicles..
Hybrids show significant benefits in CO_2 reduction and local air quality emissions but can result in significant increases in vehicle weight (especially for commercial vehicles) and cost. There are particular benefits in their use in operations that involve regenerative braking.

Other Energy storage systems using flywheels, capacitors and hydraulic systems are still being investigated but are not yet commercially or technically viable.

Pure **Battery Electric Vehicles** (EVs) offer zero emissions at point of use and have a niche in local emissions reduction but are currently limited by the range, payload, life and recyclability of storage technologies. The range can be extended by the use of a small internal combustion (IC) engine. Purchase and use of electric vehicles could also be encouraged particularly for urban fleets of light vehicles under local authority control where creation of a communal battery charging infrastructure will encourage the wider adoption of such vehicles. They lose most of their environmental advantage (i.e. greenhouse gases) if electricity is made from fossil fuels. The lack of a breakthrough in on-board storage of electrical energy presently limits the power and range of such vehicles to small vehicles for urban use.

Fuel Cell Electric Vehicles Hydrogen powered electrolytic fuel cell vehicles are a very promising long term transport solution. Hydrogen can be supplied to an on-board fuel cell to produce electric power. Applications are expected to favour buses, passenger cars and light commercial vehicles initially. The hydrogen can be sourced directly in liquid or gaseous form. It needs to be clearly understood that there are significant barriers to reaching the carbon free transportation era The problems of on-board vehicle hydrogen storage, lack of infrastructure, cost of fuel cell technology, and the ability of such vehicles to compete on cost with conventional vehicles, may prevent their introduction.

Extending the use of hydrogen to heavy commercial vehicles depends on even more intensive development of fuel cells; it is not considered that spark ignition hydrogen engines offer a significant way forward for such powertrains – fuel storage becomes an even greater issue.
Fuel cell vehicles will rely wholly on the supply of hydrogen, so as a flexible interim measure, indirect methods of hydrogen distribution are being considered, for example the reformation of petroleum, natural gas or methanol either on or off the vehicle.

There is a consensus among passenger car manufacturers and their partners that hydrogen is a key fuel for the future, particularly when made from renewable energy sources. The technologies appropriate for using hydrogen as a road fuel are likely to be the electrolytic fuel cell or the familiar spark ignition engine.

Extending the use of hydrogen fuel cell engines to heavy commercial vehicles depends on even more intensive development of fuel cells and electric motors power train to achieve suitable levels of power, torque, longevity and cost. Space for hydrogen fuel storage becomes an even greater issue for some applications for both fuel cell and spark ignition hydrogen engines.

5 Fuel Options – A Discussion

The Motor Industry believes that there are new fuels and technologies that offer significant potential for the improvement of air quality and greenhouse gas emissions.

Full market saturation of new technologies is a long process. For the introduction of a major new technology, a vehicle life cycle might involve five years research and concept proving, five years design/development, seven years model life and up to fifteen years vehicle life once in the market. Some such technologies are well into the development cycle and will require the industry to make significant investment.

The applicable fuel and technology at any point in the vehicle life cycle will be different for different types and applications of vehicle. Urban transport will have different infrastructure and technology opportunities from international haulage or coach operation. Similarly, the different power to weight ratios, payloads and vehicle space limitations will probably determine different introduction timings or even different ultimate technologies for cars light commercial vehicles and trucks/buses. Applications such as captive fleets (operated in a defined area from a single base) provide opportunities for the earlier introduction of new fuels and technologies. However this may potentially incur additional costs for vehicle manufacturers and operators which may need government support similar to the current Powershift scheme. Such technologies may also have a significant detrimental effect on residual values and hence overall cost of ownership in the early days because of the inherent conservatism of owners.

Whilst vehicle manufacturers continue to develop more efficient and less polluting engines with lower CO_2 emissions (for example in cars - by wider adoption of diesel and more recently petrol and diesel hybrid engines), there is little prospect of a change to more radical technologies such as fuel cells or new fuel infrastructures such as hydrogen from renewable sources without fiscal support/incentives from Government and a long term European vision and strategy.

Fiscal measures are a key measure to encourage the adoption of alternative fuels but should only promote fuels for which there is proven environmental benefit beyond current legislated requirements and where there is adequate quality control (e.g. internationally agreed specifications or an adequately defined proprietary specification).

Central and local government has the opportunity to lead the way by purchasing less polluting vehicles which could see the establishment of the necessary fuels infrastructure and subsequent take up by the wider community. Traffic management schemes which help to keep traffic flowing freely, will have a major impact on both emissions and CO_2

Fuel options include conventional, modified and alternative liquid fuels, gaseous fuels both carbonaceous and non-carbon, and electricity which of course may also be generated by using fossil or renewable fuels. The following is a brief summary of fuels, which could play a role. More detailed information is contained in the report.

Some **alternative fuels** may be on the path to a long-term development of alternative technologies. There are, however, economic implications in fragmenting the fuel infrastructure and hence increasing the number of associated vehicle specifications.

Current Conventional Fuels have been developed and refined for over a century and even as alternative fuels are being introduced, current fuels and corresponding engine technologies continue to respond to the changing needs of society. The quality of conventional fuels should continue to be improved (with industry agreement) to the maximum extent possible to achieve rapid environmental benefits

across the whole vehicle parc. Early introduction of quasi-zero sulphur fuels will allow the latest emission control technologies to be introduced as well as reducing emissions from existing vehicles.
It is anticipated that in the absence of any viable alternative the use of conventional diesel fuel for heavy commercial vehicles will have to continue well into the middle of this century. Gasoline may have a role to play as an intermediate source of hydrogen. However, many fuel cells for example are intolerant of sulphur some requiring a purity level of less than 1ppm.

Improved or modified conventional fuels will continue to be needed to support future vehicle technology. Current petrol and diesel supplies can be supplemented by introducing a percentage of renewable materials or other extenders providing they meet internationally agreed standards and the performance and durability effects on the current fleet are taken into account. Synthetic fuels are also being developed

Fuel Extenders. Bio-fuels (bio-diesel, bio-ethanol) added in blends of up to 5% to conventional fuels marginally reduce the consumption of fossil fuels and can be used by all vehicles in service.

Bio-fuels/Oxygenates (e.g. bio-ethanol, ETBE, bio-diesel - made from a variety of domestic renewable sources) can provide renewable energy coupled with reduced exhaust emissions but when used unblended they are incompatible with most current in-service vehicles. In the case of bio-diesel the market is unlikely to be able to supply enough bio-diesel to meet more than a few percent of the total fuel demand. Use of bio diesel and bio-ethanol is supported in blend strengths up to 5%. Use of 100% bio diesel or bio-ethanol in the existing vehicle fleet will inevitably bring about serious technical problems and component damage and should be avoided for general use.
However the motor industry would generally prefer the use of **ethers** such as ETBE rather than alcohols.

Flexibly fuelled vehicles have been developed capable of using either bio ethanol or gasoline providing the benefits associated with ethanol supplemented by the convenience and flexibility of gasoline.

Synthetic fuels such as **GTL (gas to liquid)** potentially provide high quality diesel that the motor industry could utilise to benefit emissions. It could also benefit CO_2 emissions if produced from gas that would otherwise be flared. However, current evidence suggests that such fuels are unlikely to be economic or widely available in Europe but their future use should be kept under review.

Emulsions claim benefits in particulates, CO_2 and NOx. However other durability and stability concerns lead us to consider that these are niche products.

Liquid Petroleum Gas (LPG) has been introduced as an alternative to gasoline in spark ignition engines, predominantly for light duty vehicles which are more readily adaptable than heavy commercial vehicles and provides some environmental emissions (CO_2) benefit if correctly burnt. It is also being used as an alternative to diesel engines in light commercial vehicles in urban areas to reduce local regulated emissions. In recent years, a sustained effort to promote LPG use in the UK has been made by a number of vehicle manufacturers and fuels suppliers. However, as regulated exhaust emission limits become more stringent, the benefits of LPG, especially on retro fitted vehicles, will become less significant in the next 5 years.

LPG nevertheless serves as a useful introduction of alternative fuels to the general public.

Natural Gas *(*NG) liquid-LNG or compressed-CNG) has some potential benefits in view of its low carbon content relative to petrol and the widespread commercial/domestic transmission infrastructure. However, the current need for bi-fuelling compromises this potential. Such vehicles need purpose built spark ignition engines. The increase in kerb weight (due to the need for a high pressure fuel tank) and consequential payload loss together with its lower density and higher maintenance costs adversely impacts on any advantages as a commercial vehicle fuel. They also currently face high refuelling infrastructure costs but Taxation incentives on CNG/LNG allow it to be used for depot based operators.

Natural Gas has sometimes been considered as an intermediate step towards hydrogen fuelled vehicles. However the current infrastructure is not (but might have been) compatible with hydrogen, which puts into question the role of natural gas as a direct path on the route to hydrogen. The natural gas infrastructure could be used for local or on-board production of hydrogen but the production of CO_2 in the process would involve CO_2 emissions.

DiMethoxy Methane (DMM) and **Di Methyl Ether (DME)** show promise in lowering NOx and particulates. It could potentially be sourced from biomass thereby lowering CO_2 from diesel engines and continued research should be encouraged.

Hydrogen shows the greatest ultimate potential providing it can be made from renewable low carbon sources and Government is prepared to support the appropriate fiscal and research policies to enable a technology and infrastructure shift. This support is required for three main reasons:

- Conventional oil and gas based fuels which are rich in carbon are significantly cheaper to manufacture and distribute than hydrogen, especially hydrogen from renewable sources
- There is a considerable investment in the fuel distribution system and setting up a new fuel distribution system will be extremely expensive.
- There is a considerable investment sunk in the manufacture of conventional petrol and diesel engines and vehicle manufacturers will need to be sure that there is a market for new technologies.

In the short to medium term whilst hydrogen technologies are being developed and commercialised, the move to hydrogen will not be a single step but will be a long-term phased introduction. During this time other technologies will continue to be developed or improved to supplement and extend conventional fuels and improve emission levels.

Hydrogen Internal Combustion Engines

Using hydrogen directly in modified conventional spark ignition engines is a promising concept. The initial investment and production facility disruption for vehicle manufacturers is limited and the possibility of running bi-fuel vehicles for an interim period until an extensive hydrogen infrastructure supply is available eases some of the introduction problems. There is potential for improving engine efficiency by developing higher compression ratios when mono-fuel hydrogen vehicles become available.

Currently, hydrogen ignition technology has been developed and proven by at least one major manufacturer. The key obstacle to introduction is the lack of a hydrogen production, storage and supply infrastructure.

Fuel Cell Electric Vehicles

Hydrogen powered electrolytic fuel cell vehicles are a very promising long-term transport solution. Hydrogen can be supplied to an on-board fuel cell to produce electric power. Applications are expected to favour buses, passenger cars and light commercial vehicles initially. The hydrogen can be sourced directly in liquid or gaseous form or via reformed methanol, natural gas or petroleum.

Fuel cells require extremely pure hydrogen to operate (less than 1 ppm impurities in some cases). Therefore as a flexible interim measure to overcome the problems of fuel distribution, indirect methods of hydrogen distribution are being considered. The reformation of petroleum, natural gas or methanol using a miniature on-board refinery would allow the introduction of fuel cell vehicles without the need for an extensive hydrogen supply structure. Whilst the additional reforming process is not the ultimate goal, it may offer lower local emissions and an overall reduction in CO2 emissions compared to conventional petrol or diesel vehicles. However, the migration of such interim solutions to a system using a direct hydrogen infrastructure is not clear.

Fuel cell technology potentially offers high efficiency but there remain significant weight, reliability and economic challenges to resolve.

Common issues between hydrogen fuel cell and hydrogen ignition vehicles

The on-board fuel storage issue remains technically challenging both for hydrogen spark ignition and fuel cell vehicles.

On-board hydrogen can be stored in compressed or liquid form. Either way means that much larger tanks than are currently used will be needed for the same vehicle range. To achieve the same range as cryogenic liquid hydrogen tanks, compressed hydrogen tanks would need to be at a pressure of 750 bars, at the limits of current technology. Cryogenic, low-pressure tanks can be packaged more easily into vehicles than bulbous high-pressure tanks. However, more energy is required to liquefy hydrogen than to pressurise the gas. Whichever storage solution finally predominates, it is likely to be used for both fuel cell and ignition systems as the problem for both technologies is in obtaining the maximum range for the vehicle.

At this stage, both hydrogen fuel cell and hydrogen internal combustion engine vehicles are being actively developed by the motor industry and it is expected that both technologies will come to market. The maximum benefit of both technologies will be achieved when hydrogen is widely available to the public.

6 The Way Forward - Towards A Shared Vision

In the short to medium term it is expected that the vehicle parc will be dominated by vehicles using developments of existing fuels and technologies. Near term developments will include a mixture of improved conventional fuels and technologies, alternative fuels and hybrid technologies.

It is important that Industry, Government and society co-operate in the development of a long-term strategic vision of future road transport fuels, and achieve common goals. This vision needs to encompass local air quality improvement, reducing impact on global warming, and energy security. Whilst this report identifies and discusses many fuels options, it is the view of SMMT that only hydrogen offers the potential of an environmentally sustainable transport fuel in the long term – subject to the provisos stated elsewhere in this report regarding hydrogen production methods.

SMMT aims to play a constructive and key role in this process. As experience with LPG has shown, a clear and long-term implementation strategy will be required for the introduction of a hydrogen economy for road vehicles. The development of the strategy must be made with both national Government and those of the European Union. In order to prepare the industry road map (see below) towards the introduction of hydrogen it is essential that the stakeholders co-ordinate their efforts to ensure that fuels availability, power unit availability and market acceptance follow a common time line.

Figure 1

Possible Timetable For Introduction Of Alternative Fuels/Technologies

Initial applications (shown below) are expected to be cars, buses
Introduction for heavy commercial vehicles will be some way behind Source: FFSG/SMMT 2001

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bio-fuels - (as additive)		From 2003																	
Natural Gas - (in fleets)			From 2004																
Gas to liquid – (as additive)									From 2010										
Petrol Hybrids	Running now and likely to increase																		
Diesel Hybrids		From 2003																	
Hydrogen - Fuel Cells				Limited availability from 2005							General availability from 2012								
Hydrogen - combustion fuel				Limited availability from 2005							General availability from 2012								
LPG	Running now but advantages will diminish																		
Electric	Running now but future use expected to remain limited																		

The motor industry expects to have the necessary technology available for some vehicle types within this decade, although it will be the next decade before it starts to become common production.

The vision set out in the Institute for Public Policy Research (IPPR) hydrogen report of a ten year task force would be a logical first step.

National strategies for incentivising alternative fuels and technologies should be made where the use of the fuel / technology is seen to be on the development path leading to the ultimate fuels and industry should be working on the technologies appropriate to this path.

A properly supported and funded multi-stream development programme should be set up as soon as possible to raise public awareness and confidence. It should also cover fuel manufacturing/bulk storage/supply infrastructure, on-board fuel storage/handling and finally powertrain development. At the outset of this vision process, the UK automotive industry, through the SMMT, would welcome an opportunity for dialogue and engagement with Government.

Whilst care needs to be taken by the SMMT and others to allow market forces to play their role in the short term, ideally a recognisable route or routes towards using hydrogen as a fuel should be developed. Natural gas and methanol could feature on this route.

The Government strategy regarding future fuels should be as clear and as transparent as possible to ensure that it gives appropriate support for suitable new fuels and is maintained so as to give the maximum potential for developing the necessary fuel(s) infrastructure as quickly as possible. This is particularly true given the diversity of current and potential fuels and the reality that not all of these can be vigorously pursued

Managing the Change to a Renewable Fuel Future

The change to a potential zero carbon transportation economy based on hydrogen will need careful management. The hydrogen revolution cannot happen overnight and some fuels such as diesel will play a pivotal role in the short to medium term to reduce greenhouse gases. There will still be a need for further improvements in conventional fuel quality to enable implementation of cleaner vehicle technology, possibly by Government incentivisation.

Matching Mobility and Fuel Needs

The attractiveness of future fuels is likely to differ according to vehicle market segment and to have different development and introduction paths. For example, urban passenger journeys as compared with international freight haulage. Any strategy for future fuels must accommodate the full range of society's diverse mobility needs, maintain the automotive contribution to the economy and must take into account the EU and International context.

The role of hydrogen in meeting future road transport needs is regarded by industry as extremely promising. It is important that existing road transport operation is considered and a route to the ultimate fuels is mapped out in both Industry and Government thinking.

On board fuel storage, whether gaseous or in liquid form, is an issue to resolve due to the low specific energy of hydrogen (kWh/L) compared to conventional liquid fuels. Another major hurdle faced and which also applies to many other alternative fuels is the lack of fuel supply infrastructure leading some vehicle manufacturers to propose the on-board reformulation of methanol, gasoline or other fuels. At this stage it is likely that hydrogen will be applicable to passenger and light duty vehicles before heavy goods vehicles.

Political Commitment

The impetus for moving to hydrogen will therefore be a clearer understanding of the seriousness of climate change and a conviction that the level of carbon dioxide is a critical factor. Without such a political understanding and commitment, it is unlikely that the necessary fiscal action will be forthcoming.

7 Implications for UK Industry Competitiveness

A market shift towards hydrogen, especially renewable hydrogen, could provide significant opportunities for the UK energy industry in the fields of production, storage and distribution. For vehicle manufacturers, a market shift toward fuel cell technology, or a similar technological dislocation from current reciprocating IC engine technology for road vehicles (and also non-road engines), would have significant implications for UK engineering and manufacturing employment. This will affect engine manufacture, and the competitiveness of new vehicle assembly and associated component suppliers and service industry. Detailed consideration of this matter is outside the scope of this report. There is a concern at SMMT that the UK will not be among the countries that host the engineering and scientific centres that currently lead in developing fuel cell technologies and evolving these technologies for volume manufacture.

Consequently, SMMT considers it appropriate to register its concern and to recommend to Government that it should identify and consider all possible implications of potential options for a sustainable future fuel and road vehicle technology strategy, and the policy measures to support the strategic objectives.

8 Recommendations

Potential Policy Signals for Government:

General:

1 Policy approaches need to consider the influence of product life cycle on technology introduction including the time needed for product development and validation followed by a phased introduction to gain customer acceptance.

2 Policies need to recognise and be compatible with an EU wide and potentially world wide approach

3 Short term policies should be synergistic with the long term strategic vision

4 Policy initiatives must be targeted, well resourced and of sufficient longevity to ensure effectiveness and develop confidence, bearing in mind the full life cycle of a product is typically 20 years.

5 Policy approaches must be developed based on pan European emissions performance standards for vehicles.

6 Only fuels for which there are fuel standards should be incentivised. Objective criteria are needed to assess the relative merits of different fuels and technologies and should be on a well to wheel basis

7 There needs to be revision of planning policy guidance to support the wider availability of refuelling facilities for alternatively fuelled vehicles

8 Public authorities should be encouraged to lead by example within an EU framework.

9 There needs to be continued long-term support for research and development into technologies showing promise

Hydrogen:

SMMT considers that hydrogen shows the greatest ultimate potential providing it can eventually be made from renewable low carbon sources and therefore makes the following specific recommendations:

1. Government must be prepared to support the appropriate fiscal and research policies to enable a technology and infrastructure shift.

2. Account should be taken of the fact that the rate of introduction will be dependant on developments in fuel storage and power units.

3. Government policy should recognise that the rate of uptake is likely to be different for passenger cars, light commercial vehicles, public transport and haulage.

4. Government should establish a Hydrogen Research Programme for R&D into the hydrogen economy. This could be linked to or funded by The Carbon Trust.

5. Government should establish a Hydrogen Taskforce to develop and manage a minimum 10-year hydrogen introduction strategy. This would include:-

    a. a Hydrogen Infrastructure Fund and a 'Hydrogen Shift' Capital Grant. Both could be managed by the Energy Savings Trust.

    b. a voluntary Hydrogen Fleet Promotion Scheme for companies and local authorities that agree to replace a proportion of their fleets with hydrogen vehicles

    c. incentivising Hydrogen fuelled vehicles within company car taxation and VE.

6. For an introductory period, hydrogen should be tax and duty free

7. Government should support the development of methods for the production of hydrogen from renewable sources.

8. Provided that sufficient hydrogen can be produced to satisfy the needs of road transport, the provision of hydrogen should be part of a wider energy policy.

9. Once the hydrogen infrastructure and product acceptance is fully established, the excise duty on all motor vehicle fuels should be progressively restructured based on the vehicle's contribution to global warming in production, distribution, use and disposal. This method would allow Governments to provide the lowest taxation levels for renewably produced hydrogen fuels and encourage the transfer to a hydrogen economy.

10. Government and industry should participate in the development of international standards.

11. Government should establish a Hydrogen Outreach Programme for educating people about hydrogen safety and raising awareness.

Fuel Cell Electric Vehicles:

Fuel cell electric vehicles represent a most promising long-term emerging drive-train technology. Government should provide support for early development including funding for demonstration and pilot projects. .

Interim Measures

Conventional Liquid Fuels – Diesel and Gasoline

Government should support the early and widespread introduction of Brussels proposals for zero sulphur fuels as advocated by the EP Rapporteur Ms Heidi Hautela during 2001.

The implications of changes to any other fuel characteristics (e.g. aromatics, viscosity, lubricity, and density) must be understood. Changes can only be agreed if they are deemed not to adversely affect the fuel injection equipment (FIE)/engine performance and durability.

Liquefied Petroleum Gas (LPG)

To support the commitment made by manufacturers, who have invested heavily to develop the LPG market in response to Government policy, fiscal incentives should continue. LPG serves as a useful introduction of alternative fuels to the general public.

Government and industry should co-operate in the development of conversion standards.

Natural Gas

Provided that the infrastructure is capable of conversion to hydrogen, fiscal incentives should continue for CNG to serve as a useful introduction of alternative fuels to specific public authorities (e.g. buses and refuse collection vehicles) and other depot-based operations.

Bio fuels

Government fiscal incentives should be provided for bio-diesels serving as extenders for conventional diesel fuels if shown on a life cycle basis for UK production that they are CO_2 beneficial. Likewise the same should apply for any incentives in the UK for bio-ethanol either as 5% blend or 85% blend.

The development of European standards should continue for fuels containing bio diesel not exceeding 5% blend at any filling point.

ANNEX

INTRODUCTION

ENERGY STORAGE, TRANSMISSION & UTILISATION FOR AUTOMOTIVE USE

Practical mobility requires that the vehicle be supplied with a source of power in a manageable, containable form providing sufficient energy density for the application.

Current vehicles rely on the chemical energy stored in liquid (or gaseous) hydrocarbon fuels to provide a fuel with high energy density, thus providing a high level of energy availability with low storage volume. A typical carbon-hydrogen bond energy is in the range of 300 to 700 kJ per mole and so petrol, for instance, has a calorific value of around 43 MJ/kg, methanol just under 20 MJ/kg.
The energy contained in that fuel is released in the process of combustion and transferred into mechanical energy via the movement of the pistons and then transferred via mechanical linkages, gears etc to the road wheels.
Power outputs of internal combustion engines are normally in the range 50 to over 400kW.
All combustion engines thus rely on the fuel for ‘chemical’ energy storage, whether it is gaseous or liquid, carbon-based or carbon-free. Range (for a given power output) is therefore a factor of the tank volume and the energy content of the specific fuel. The fuel storage system life is limited only by the life of the container materials.

Rather than using liquid or gaseous fuels to store chemical energy, current electric vehicles rely on a battery to store and release electrical energy. Mechanical power is derived directly from it via an electric motor, which can be used (directly or indirectly) to power, the road wheels.
The electrical energy must first be generated off the vehicle and hence may be generated from fossil fuels, renewable hydrocarbon fuels, or non-carbon energy sources such as hydroelectric schemes, wind power or wave power.
Range (for a given power output) is therefore a factor of the storage capacity of the battery, which in turn will vary with type and with physical size. It may be limited by the physical mass of the battery. The fuel storage system life is limited by the number of times which the battery can be recharged before requiring replacement.

On-board "fuel cells" may be a practical solution combining the benefits of producing mechanical energy directly from electricity with the use of chemical energy storage. This may be either by on-vehicle storage and direct use of hydrogen with the fuel cell, or by the addition of a reformer to convert more conventional fuels into hydrogen, either on-board or at the refuelling station.

1 ELECTRICITY AND ELECTRIC VEHICLES (EVs)

Electric vehicles are often seen as totally "clean", but this depends on how electricity is generated. Hydroelectric, tidal, wind or solar power stations are among the few truly clean options. In the shorter term electric vehicles may satisfy niche markets mainly for captive (urban) fleets. Purchase price may be higher.

Several auto producers now offer EV cars and trucks for sale or lease in Europe, in Arizona, and in California which mandates large numbers of EV purchases by 2003. Consumer response so far to the new vehicles has been encouraging but very limited in terms of actual purchase/leases, despite subsidised prices and generous tax credits. Carmakers are also working on hybrid gasoline-electric vehicles, which could increase travel range (see section 1).

What is Electric Fuel?

Most liquid & gaseous fuels release stored chemical energy in an internal combustion engine, which converts this to mechanical power at an overall rate of 25-40% of the potential energy in the fuel. Electricity is unique among the alternative fuels in that mechanical power is derived directly from it via an electric motor and this direct use of electrical energy results in an energy conversion efficiency of 80 - 90%. However, transmission efficiencies substantially reduce this figure to levels more comparable to conventional IC engines.
Electricity is commonly stored in batteries, but fuel cells (which convert chemical energy to electricity) are also being explored.

Benefits

There are no toxic (or noise) emissions at the point of use. The emissions associated with the production of electricity depend on how the electricity is generated. As noted above electric vehicles are up to 90% efficient although current production and distribution efficiencies are such that overall efficiency is reduced to 17% behind gasoline at 19% and diesel at 21%. When electricity is produced from renewable non-carbon sources (wind, wave, solar, hydroelectric) there a clear greenhouse gas advantage in power generation and use. However there are significant greenhouse gas implications .in battery manufacture, replacement and disposal. The economies of using EVs once the relatively high initial capital cost is made, comes with the lower "fuel" and maintenance costs. The cost of an equivalent amount of fuel for EVs is less than the price of gasoline. Also, maintenance for EVs is less—EVs have fewer moving parts to service and replace although this is offset by the need for battery replacements. Some fiscal incentives exist to encourage individuals or fleet operators to purchase Alternatively Fuelled Vehicles, and local authority benefits - free parking/charging, use of bus lanes etc are being developed.

Issues

The big issue is "How will the electricity be created". Renewable sourcing, hydroelectric, wave generation, wind, solar power etc provide a genuine zero emission option, but if electricity is produced from coal the environmental benefits are markedly reduced.
There is also the efficiency issue. As an illustrative example, an electric vehicle, converting maybe 75% of the energy supplied into useful work, loses much of its advantage if "fuelled" with electricity produced by a coal fired power station which typically throws

away two thirds of the raw energy. In contrast about 80% of the energy available in raw crude oil reaches the vehicle petrol tank (- energy used in extraction, refinery and distribution) but 80% of that energy is then thrown away because of the inefficiencies of the IC engine vehicle. Hence the importance of well to wheel comparisons.

The next issue is energy storage on the vehicle. Current battery technology only allows electric vehicles to have a limited operating capability using battery power (typically 80-130 km range and 90km/h max speed). A combined research effort (automakers, battery manufacturers, electric companies and government) is working to develop longer-range batteries. Amongst the various battery technologies being evaluated are lead-acid, nickel nickel-cadmium, nickel nickel-iron, nickel nickel-zinc, nickel nickel-metal hydride, sodium sodium-nickel chloride, zinc zinc-bromine, sodium sodium-sulphur, lithium, zinc zinc-air, and aluminium aluminium-air. However, no practical, economically viable breakthrough technologies have materialised in spite of many years' research.
On-board "fuel cells" e.g. fuelled by hydrogen, methane or ethanol may be a practical solution where the chemical energy is stored in the fluid.

It remains to be determined how recharging a large number of such battery electric vehicles might affect the grid. However at current expected sales levels this will not be an issue in Europe. Estimates suggest that if all vehicles became electric, electricity power generation would need to double. Some utilities in the USA have developed special time-of-use meters and off-peak electric rates to separately monitor EV electricity usage from the home and provide incentives to recharge at night when the overall load is down or other off peak times.

2 HYDROGEN

What is hydrogen?

Hydrogen gas (H_2) is a gas at normal temperatures and pressures. Most commercially produced hydrogen is currently not pure hydrogen gas but contains small amounts of oxygen and other gases. This is adequate for spark ignition hydrogen engines, but higher purity levels are currently required for fuel cells. The specification for commercial automotive fuel hydrogen is yet to be defined. Town gas consisting of hydrogen and CO had been used for many years in the US.

How is Hydrogen Made?

A number of methods can be used to produce hydrogen. However, currently the most common is synthesis gas production from steam reforming or partial oxidation. Another route likely to become much more extensive is electrolysis.

The predominant method for producing synthesis gas is steam reforming of natural gas, although other hydrocarbons can be used as feedstocks. For example, biomass and coal can be gasified and used in a steam reforming process to create hydrogen.

Hydrogen could be produced from many bio-fuels but all these solutions continue to partially use carbon fuels and should be considered as a possible pathway to the ultimate twin goals of a renewable fuel zero emission transport system

Hydrogen can be made directly from water. Electrolysis uses electrical energy to split water molecules into hydrogen and oxygen. The electrical energy can come from any electricity production sources including renewable fuels.

Benefits

Hydrogen can be used in either adapted internal combustion engines or in fuel cells powering electric vehicles. However like any energy carrier (carbon fuel, electricity etc) it has to be manufactured and distributed but there is the prospect that if renewable electricity is used to produce hydrogen by electrolysis of water then ‘zero emission mobility’ could become a reality.

Hydrogen used in fuel cells produces no direct harmful emissions (toxic emissions, greenhouse gases, noise) and only produces water vapour. Emissions may, however, be generated in hydrogen production.

Unlike all other combustible fuels hydrogen also burns with no harmful emissions other than oxides of nitrogen resulting from high temperature combustion. This can be controlled by lean burn concepts or by using different types of catalytic converters.

40-65% of the energy in hydrogen can be converted by a fuel cell into electricity although if used to fuel an IC engine the energy efficiency may be halved.

Issues

Hydrogen has probably the highest energy content per unit mass (120.7 kj/kg) and on a mass basis it has 2.6 times as much energy as the equivalent mass of gasoline. HOWEVER it must be liquefied (-253ºC) or compressed to contain sufficient energy appropriate for a mobile application. Liquefying absorbs 25% of its energy, using 5kW to liquefy each 0.45kg. More effective ways to store hydrogen eg hydrides are being studied but they still store relatively little energy per unit mass.

After production, the key issue for hydrogen is distribution, and the need to develop an adequate fuel supply network.
Until such time as renewably produced hydrogen is widely available at filling stations (which could be many years away), fuel cell electric vehicles may, as an intermediate solution, use hydrogen derived from carbon fuels.
Options include:

- using the existing fossil fuel supply infrastructure (e.g. petrol) and producing the hydrogen on board the vehicle using an on-board reformer.
- developing a methanol or natural gas distribution network and again producing the hydrogen on board the vehicle, or
- using hydrogen locally produced from natural gas and storing the hydrogen on-board the vehicle directly.

An interim strategy for hydrogen ignition vehicles would be to employ two storage tanks; one for hydrogen and one for petrol to allow bi-fuel operation where limited hydrogen refilling stations exist. Because hydrogen has a low specific energy, having decided how to produce it, the next question is – how can it be stored on the vehicle in sufficient quantities. (e.g. compressed, liquefied, chemical bonding with a storage material such as metal hydrides).

Safety Issues

As with any compressed fluid, compressed hydrogen fuel tanks have the potential to explode and there is perhaps a public perception that hydrogen is dangerous but in reality it is certainly no less safe than gasoline. Hydrogen, being lighter than air, rises on release i.e. will not soak into fabrics or puddle. OK but what if it ignites? The Rocky Mountain Institute (USA) described tests conducted at the College of Engineering at Miami University where 3000 cubic feet per minute of hydrogen were allowed to leak from a vehicle tank and set alight. During combustion, temperature sensors inside the vehicle showed a temperature rise of no more than a couple of degrees centigrade anywhere inside the vehicle because hydrogen burns without much radiant energy.

Hydrogen - Industry View

The role of hydrogen in meeting future road transport needs is regarded by the automotive industry as extremely promising. There is a consensus among vehicle manufacturers and their partners that hydrogen is a key fuel for the future, particularly when made from renewable energy sources.

Sourcing and distribution of hydrogen and the cost of the new technology and of the fuel itself are issues subject to ongoing analysis and development and need to be linked to a **long term strategy** in the field of environmental taxation. Such a strategy would enable the intermediate initiatives of vehicle manufacturers outlined above to be put into context and to receive appropriate Government encouragement. The extent to which a selective provision of hydrogen from non-sustainable sources can be environmentally acceptable in the short/medium term also needs to be understood in the context of a transition strategy towards a sustainable renewable hydrogen infrastructure. The SMMT affirms its support of the use of hydrogen as the future fuel for road transport. It encourages the UK government to work with its industry partners to promote and sustain this development and is ready to play its own part in this process.

3 FUEL CELL ELECTRIC VEHICLES

What is a Fuel Cell?

The first fuel cell is reputed to have been constructed by Sir William Grove in 1839 with significant further research in Germany during the 1920's. The first practical examples were used over many years in the US Apollo space programme.

The fuel cell is an electrochemical device that converts the chemical energy of a fuel directly into usable electricity, heat (and water) without combustion as an intermediate step. Fuel cells are similar to batteries in that both produce a direct current by means of an electrochemical process. In both systems, two electrodes, an anode and a cathode, are separated by an electrolyte. Unlike batteries, however, fuel cells store their reactants (hydrogen and oxygen) externally, and operate continuously as long as they are supplied with fuel. At the anode, hydrogen atoms are split by a catalyst into hydrogen ions (protons) and electrons. The hydrogen ions then travel through the electrolyte to the cathode. Simultaneously, the electrons move through an external circuit to a load generating a current (which is used to drive the vehicle) and then to the oxygen electrode. There the oxygen, hydrogen ions, and electrons combine on a catalyst to form water.
Fuel cells are combined into groups called "stacks" to achieve a useful voltage and power output. Fuel cells running on hydrogen emit almost none of the sulphur and nitrogen compounds released by conventional generating methods, and can convert up to 65% of the energy in hydrogen into electricity. The hydrogen used can be generated by a wide variety of fuels if a fuel processor is used to release the hydrogen contained in them, but this may then result in emissions (including some CO_2 from the reforming process).

Some Examples of Types Of Fuel Cell – see also table 19

Phosphoric acid
Proton exchange membrane or solid polymer
Molten carbonate
Solid oxide including intermediate temperature solid oxide
Alkaline
Direct methanol fuel cell
Regenerative fuel cell
Zinc air fuel cell
Protonic ceramic fuel cell

Applications range from utility power plants to cell phones/laptops and not all of the examples noted above would be suitable for automotive use. *(for further information see www.fuelcells.org)*

Benefits

Fuel cell technologies may enable highly efficient, low- or zero-emission and potentially zero CO_2 vehicles. Fuel cell vehicles substantially reduce the number of moving parts required (compared to internal combustion engines) and thus could ultimately become, cost-competitive. Prior to the widespread introduction of hydrogen infrastructure, fuel cells have the potential to provide fuel-flexible vehicles.

Issues

Substantial effort is being expended in overcoming critical technical barriers (high cost low performance) to automotive fuel cell development. The size, weight, and cost of automotive fuel cell components must be reduced and performance improved to make fuel cell power systems competitive with currently available alternatives. Infrastructure and fuel availability issues need to be resolved – the options are discussed below. As this was being drafted, news is arriving of a new fuel cell delivering 1.75kW/litre an increase of 60% over any other fuel cell and producing 134hp continuous (173hp peak).
Current fuel cells are generally intolerant of impurities in the fuel, have a relatively short life span and use large amounts of precious metals.

Fuels for the Fuel Cell

Hydrogen is the Ideal Fuel

Fuel cells operate best on extremely pure hydrogen. Storing hydrogen on board a fuel cell vehicle is the most desirable option and greatly simplifies the propulsion system design by not requiring on-board fuel processing. It also results in a more energy efficient system. Because hydrogen is normally a gas, an relatively huge large volume is would be required to contain enough energy to provide the same driving range as today's automobiles. Currently a way of 'concentrating' the hydrogen is required. There are two methods of storing hydrogen on board a vehicle that are receiving the most attention: namely, compressed gas in storage tanks at high pressure or liquid hydrogen in insulated storage tanks at low temperature (–253ºC) and low pressure. Other storage methods based on metal hydrides, solid adsorbents, and glass micro spheres have potential advantages but are not as well developed. There is no reason why hydrogen storage systems cannot be as safe as the fuel systems in current automobiles.

Fuel Processors to Reform Common Transportation Fuels into Hydrogen

Fuels cell vehicles can only operate using hydrogen. They have to carry fuel around with them. As there is currently no existing hydrogen distribution system, there is a typical 'chicken and egg' situation. Vehicle manufacturers will be are unwilling to produce and sell fuel cell vehicles if there are no fuel stations. Fuel infrastructure providers will be unwilling to invest heavily in infrastructure if there are no vehicles requiring the fuel. This problem has encouraged a number of manufacturers to examine alternative ways of providing hydrogen for fuel cell. These are based on installing an additional 'miniature refinery' on-board the vehicles to convert other, more common or more easily distributed fuels to hydrogen.

In order for fuels other than hydrogen to be utilized utilised by fuel cells, they must be processed or reformed to provide an extremely pure hydrogen-rich gas mixture. Catalysts are used to facilitate the chemical reactions. The two primary types of reformers being developed for transportation are steam reformers and partial oxidation reformers. Steam reformers have higher efficiency but partial oxidation reformers are simpler. Both require relatively high-temperature operation. Because current fuel cells require pure hydrogen to run effectively, impurities (primarily carbon monoxide) in the reformer product gas stream must be removed. This can be achieved with water-gas shift reactors, preferential oxidation reactors, or hydrogen separation membranes which all add to the space already taken up by the fuel cells and storage systems.

Information derived from many sources including ecoworld, UTC fuel cells (formerly ONSI, Hydrogen & Fuel Cell Letter, American Hydrogen Association.

4 HYDROGEN INTERNAL COMBUSTION VEHICLES

What is hydrogen internal combustion?

Hydrogen can be used to replace petrol as a fuel in spark ignition engines. In principle, this is similar to the use of LPG or natural gas. Modifications to the airflow and ignition timing systems are needed to take account of the high energy content of the fuel.

Benefits

Spark ignition technology has been under continuous development for more than 100 years and the knowledge base is very high. Such engines have an extremely high output per kilogram of weight and provide driving and performance characteristics understood and accepted by the public, The use of spark ignition technologies fuelled by hydrogen would enable vehicle manufacturers to maximise the use of substantial existing manufacturing capacity. The additional hardware necessary to enable the engine to use hydrogen is not excessive. Using bi-fuel vehicles as an interim solution alleviates one of the most significant handicaps of developing new fuel infrastructures

Issues

Because hydrogen is normally a gas, a huge volume would be required to contain enough energy to provide the same driving range as today's automobiles. A way of ‘concentrating’ the hydrogen is required. The two methods of storing hydrogen on board a vehicle receiving the most attention are compressed gas in storage tanks at high pressure or liquid hydrogen in insulated storage tanks at low temperature and pressure. Other storage methods based on metal hydrides, solid adsorbents, and glass micro spheres have potential advantages but are not as well developed. There is no reason why hydrogen storage systems cannot be as safe as the fuel systems in current automobiles.

As there is currently no existing hydrogen distribution system, there is a typical ‘chicken and egg’ situation. An interim strategy for hydrogen ignition vehicles would be to employ two storage tanks, one for hydrogen and one for petrol to allow bi-fuel operation where limited hydrogen refilling stations exist.

Hydrogen burns with no harmful emissions other than oxides of nitrogen. As in fossil-fuel engines these result from the high temperatures of combustion ‘fixing’ nitrogen from the air. As this is the only pollutant this can be controlled by catalytic action.

5 CONVENTIONAL LIQUID FUELS – Diesel

Essential to current and forthcoming exhaust emission standards applicable to compression ignition engined road vehicles is Diesel fuel meeting the requirements of the Worldwide Fuel Charter – category 4. Particularly for heavy-duty commercial vehicles a requirement for this fuel is foreseen well into the mid 21st century. A similar case is true for lighter duty Diesel and Diesel hybrid vehicles.

The continued improvement in conventional fuels is foreseen and their introduction carries an immediate benefit across the entire vehicle parc. Reduction of sulphur levels will allow introduction of new technologies intolerant to sulphur. For example many fuel cells are contaminated by sulphur levels above 5ppm.

Studies at Minnesota University showed that removal of sulphur from fuel virtually eliminates formation of nano particles – which current evidence suggests could be responsible for most of the health effects associated with particulates.

Fuel viscosity, density and lubricity need to be maintained at present levels and other changes in fuel quality should only be adopted following discussion and agreement with industry. As an example, reduction in poly aromatics (polycyclic aromatic hydrocarbons PaH) may be desirable. There is scope for substantial reduction from present levels (currently ~35% total aromatics) and the ACEA world wide fuels charter recommends a maximum of 15% in total aromatics (2% PaH) for fuels to be used on engines fitted with advanced emission control devices.

However in reducing total aromatic content for fuels this may have an adverse effect on older engine and fuel injection elastomer components (seals etc).

5A REFORMULATED DIESEL

As with petrol, processes are being developed to reformulate diesel fuel - specifically to reduce particulates and NOx. An example is the Fischer Tropsch process which enables diesel to be produced from natural gas and tends to have high Cetane (- which tends to reduce NOx and particulates) and extremely low sulphur content (- which also reduces ultrafine particulates). However in the latter fuel the extra refinery energy needed results in greenhouse gas emissions increases of 15%. An additional drawback is that the cold start properties are not so good making the fuel unsuitable for extremely cold conditions.

5B MODIFIED FUELS – WATER IN DIESEL EMULSIONS

Incorporating water in diesel generally yields reduced NOx + PM emissions. Some Governments (e.g. Italy, France) incentivise such fuels to improve urban air quality.

The concept of adding water to fuel with consequent benefits in terms of combustion delay and reduced peak combustion temperature have been known for many years. FIE companies in the UK were investigating this in the 1970s.

Currently available examples of a water emulsion fuel for diesel engines are PuriNOx™, marketed by Lubrizol and Aquazole™, marketed by TotalElfFina.

With the appearance of milk it consists of diesel fuel plus purified water (the latter encapsulated by surfactants to ensure that the emulsion has similar properties to diesel in terms of corrosion and operation.

Claimed benefits of PuriNOx™ Diesel Emulsion

Combustion is delayed and claimed to improve with significant reduction in particulates (up to 25%), smoke (up to 80%) and carbon dioxide (up to 12%). Lower combustion temperature also reduces NOx. (up to 15%)

The emulsion can be used on existing diesel fleets with no engine modifications or retrofit components required, but possibly with some performance penalty. The fuel can be supplied and delivered in bulk by tanker to a storage tank in the same way as conventional diesel.

Issues

Engine durability has been proven in demanding bed dynamometer tests and 1-year trials but longer-term data is not yet available. Fuel Injection Equipment manufacturers share concerns that emulsion instability could lead to a reduced fuel storage life and long term durability due to corrosive effects. National fuel specifications in France and Italy address the former point by including a centrifuge stability test. Flash point limits in these specifications alleviate potential safety concerns related to possible blending with alcohols such as ethanol.

For French National Specification for Water-in Diesel Emulsion Fuel: see appendix

5C ALCOHOL EMULSIONS (DIESEL OR GASOLINE)

Incorporating alcohol in gasoline and diesel can on some engines in certain conditions yield benefits in terms of reduced NOx + PM emissions.

Issues

There are some concerns on engine durability, shorter fuel storage life and instability, also slight safety concerns e.g. diesel blended with alcohols such as ethanol, reduces flashpoint significantly affects current storage and handling procedures, could result in reclassification of the fuel (with major implications) and may give concerns on equipment such as in-tank pumps.

6 CONVENTIONAL LIQUID FUELS -– GASOLINE (PETROL)

Essential to current and forthcoming exhaust emission standards applicable to spark ignition engined road vehicles is gasoline meeting the requirements of the Worldwide Fuel Charter – category 4. In the future, gasoline may also have a role to play as an intermediate source of hydrogen in fuel cells.

As an example of newer fuels, Shell has introduced Optimax gasoline with an octane rating of 98.6, usable on a wide range of vehicles. Using a synthetic carrier it has a good detergent which minimises deposit formation. It is low sulphur and has a lower final boiling point with a reduction in the heavy end.

Issues (general)

Work in progress to reduce emissions, including noise and to improve fuel economy is predicated on no deterioration in fuel quality e.g. density.

Additives - specifically lead replacement petrol additives

There are grave concerns regarding the use of metal (and other) fuel additives such as Ferrocene (Iron based) or Methylcyclopentadienyl Manganese Tricarbonyl (MMT) in lead replacement and/or unleaded petrol and the consequent effects on catalysts and other aftertreatment systems and onboard diagnostic systems (OBD) potentially leading to degradation of catalyst, sensor malfunction, spark plug fouling and premature wear plus increased emissions. Some of these effects could result in the Malfunction Indicator Lamp (MIL) being lit.

As with all fuels, any development of fuels specifications including additives must recognise that the fuel could be used by vehicles operating in any part of the EU (or indeed the wider Europe) and such fuel must be compatible with all in-service vehicles.

6A REFORMULATED GASOLINE - see also oxygenates

What Is Reformulated Gasoline?

Reformulated gasoline (RFG) is a general term for gasoline that has modified composition and characteristics designed to improve vehicle emissions. In the U.S.A. it specifically refers to gasoline that is blended such that, on average, it significantly reduces Volatile Organic Compounds (VOC) and air toxics emissions relative to conventional gasolines, although RFG fuel parameter values are still well within the ranges for conventional gasoline.

Benefits

During summer Reid vapour Pressure (RVP) which is a measure of evaporability, is reduced to provide most of the RFG VOC emission reductions.
Substantial air toxics emission reductions in RFG are provided mainly by reducing benzene content

Use of Oxygenates in RFG

Oxygenates (which add oxygen to gasoline to produce a cleaner burning fuel), were required to be present at 2% by weight in RFG as a result of the US 1990 Clean Air Act (although at lower concentrations than in gasohol or "oxygenated fuels"). Oxygenates have generally been represented by Methyl Tertiary-Butyl Ether (MTBE) and Ethanol (EtOH). In 1990, EtOH was present in nearly 7% of the U.S. gasoline pool and MTBE in nearly 25%. Oxygenates have been used as gasoline extenders and octane enhancers in gasoline since the 1970's without known problems at that time. Their use was increased substantially with the commencement of the US Federal oxygenated fuel program (introduced to control CO in 1992) and the RFG program (introduced in 1995) limiting blends to 15% max. The RFG program also reduces emissions of toxic air pollutants such as benzene, a known human carcinogen.

Issues

Changing from conventional gasoline to oxygenated RFG results in a one to three percent fuel economy loss.
Use of oxygenates primarily reduces CO under open loop conditions, but depending on calibration can adversely affect NO_x.
There are safety issues associated with the most common oxygenate MTBE and it is being phased out in the USA in favour of Ethanol as a result of concerns that it may leach into groundwater from corroded underground storage tanks.
As a result of different regulations and enforcement in Europe, this is not considered to be an issue by most European governments.

7 BIOFUELS (Biomass)

Biofuels are alcohols, ethers, esters, and other chemicals made from cellulosic biomass such as herbaceous and woody plants, agricultural and forestry residues, and a large portion of municipal solid and industrial waste. Biofuels include fuels used for power generation but we will focus on automotive use including bioethanol, biodiesel, biomethanol, and pyrolysis oils.

Biological material can be used as automotive fuel in several ways:
– Plant oils (rapeseed (colza), soybean, sunflower, etc.) can be converted (by transesterification process) into a diesel substitute to be blended with conventional diesel or burnt as a sole fuel.
– Sugar beets, cereals and other crops can be fermented to produce alcohol (bio-ethanol) which can either be used as a component in gasoline, or as motor fuel in pure form. Future developments may also make it possible to produce economically competitive bio-ethanol from wood or straw material.
– Organic waste material can be converted into automotive fuel as follows:
    waste oil (cooking oil) into biodiesel,
    animal manure and organic household waste into biogas
    plant waste products into bio-ethanol.

Quantities are limited in most cases, but raw materials are free and waste recycling costs are reduced.

In the medium term, other liquid and gaseous biofuels produced by thermochemical processing of biomass such as bio-dimethylether, bio-methanol, bio-oils (pyrolysis oils) and hydrogen could become competitive.

What Are The Benefits

They are a renewable and inexhaustible source of fuel, which can produce lower atmospheric pollution than petroleum fuels.
They are potentially $C0_2$ neutral.
They can use wastes that currently have no use.
They can be domestically sourced to reduce dependence on foreign oil, an issue that came into sharp relief following the increases in oil prices in 1973.

Issues – *specific issues for bio diesel and biogas are included in their respective sections*

Bio fuels are expensive and the energy consumption in producing bio diesel is such that roughly half of the CO_2 benefit is offset in the production process - more so for bio-ethanol. This offset can be reduced by fuelling the production process with waste material from crops (straw), but this tends to further increase costs.
The maximum overall bio fuel substitution is usually considered around 8% of present gasoline and diesel consumption if bio fuel production was restricted to the 10% of agricultural land presently covered by the set aside regime.

In certain circumstances there may be an increase in unregulated emissions which can be respiratory irritants and therefore an air quality penalty.

Overall

Whereas bio fuels will hardly be seen as a long-term high volume substitute for motor fuels because of the limitation of available land, they merit attention in the short to medium term because they can be applied to existing vehicles using the current distribution system and thus do not require expensive infrastructure investment, provided they are used as blending components rather than substitute fuels.

8 BIODIESEL

The pioneer diesel engine of 1895 used vegetable oil and Rudolf Diesel's demonstrator vehicle of 1900 used peanut oil.

What is Biodiesel?

Bio-diesel (mono alkyl esters) is a variety of ester based oxygenated fuel made from domestic renewable resources (plant oils/animal fats) and includes all fatty acid methyl ester (FAME) fuels that can come from a variety of sources including
VOME - Vegetable Oil Methyl Esters such as
    SOME/SME - Soya Bean Methyl Esters, Olive oil
    RAME/RME - Rape Seed Methyl Esters, peanuts, cottonseed, sunflower seed, hemp.
UVOME – Used Vegetable Oils, fuels made from [re-]used (recycled) cooking oils (known in the US as 'Yellow grease')
TME – Tallow Methyl Ester, animal oils including waste oils resulting from the rendering of animal carcasses.
- Also Ethyl Esters such as
REE – Rape Ethyl Ester and E – Soy Ethyl Ester
Use of unmodified vegetable oils results in severe deposit formation and hence use of their esters is preferred.

Because it has similar properties to diesel fuel, bio-diesel is an alternative fuel capable of being successfully used directly in any existing, unmodified diesel engine and can be blended in any ratio with diesel fuel (but see materials compatibility concerns where blend strengths exceed 5%). Bio diesel can be stored anywhere that diesel fuel is stored and maintains the payload capacity and range of diesel. Properties may differ slightly in terms of energy content, cetane number or other physical properties.

How is Biodiesel Made?

Currently, bio diesel is produced by a process called transesterification whereby the vegetable oil/animal fat is first filtered, then processed with alkali to remove free fatty acids. It is then mixed with an alcohol (usually methanol but can also be ethanol) and a catalyst (typically sodium or potassium hydroxide), reacting to form fatty esters such as methyl ester or ethyl ester, and glycerol, which products are then separated and purified. Glycerol (used in pharmaceuticals and cosmetics) is produced as a co-product.

Biodiesel Fuel Market

Much interest in bio diesel production comes from the farming industry faced with an excess of production capacity, product surpluses, and declining produce prices and its use has grown dramatically during the last few years. Soybeans contain about 20 percent oil and it takes about 0.73 kg of soybean oil to produce a litre of fuel (1 bushell of soybeans to produce 1.5 US gallons of biodiesel). The rapeseed used in Europe has an oil content of about 40 percent but some other oil seeds contain as much as 50 percent oil. In the UK a hectare of land is required to produce a tonne (1100 litres) of biodiesel from rapeseed oil. (Bio Fuels Northern Ireland)

Benefits: where used 100% neat

Pure bio-diesel is 11% oxygen by weight and for this reason combustion may provide significant reductions in pollutants. Initial analysis suggests that the CO_2 benefits are not that significant but when CO_2 absorption during plant growth is factored in the benefits become worthwhile. The lifecycle production and use of bio-diesel is claimed to produce at least 50% less carbon dioxide and other greenhouse gas emissions, plus substantial reductions in total unburned hydrocarbons and aromatic hydrocarbons, plus modest reductions in particulates and carbon monoxide compared with diesel fuel.
Biodiesel works well with new technologies such as catalysts (which reduces the soluble fraction of diesel particulate but not the solid carbon fraction), particulate traps, and exhaust gas recirculation (potentially longer engine life due to less carbon).

The impact with types of bio-diesel other than RME is difficult to quantify because fuel characteristics can vary so much. Based on Ames Mutagenicity tests in the US, bio-diesel is claimed to provide a 90% reduction in cancer risks, but other work in Europe (notably a recent Swedish report) casts doubt on this. Bio-diesel is safe to handle and transport because it is as biodegradable as sugar (but see stability problems), 10 times less toxic than table salt, and has a much higher flashpoint than diesel fuel.

Issues:

Bio-diesel in HGVs may provide a significant increase in nitrogen oxides. It is estimated that the maximum feasible replacement of conventional diesel fuel by bio-diesel (assuming use of "set aside" land only) amounts to about 5%. Because of materials compatibility and stability problems with bio diesel (discussed below) the motor industry recommends that the fuel should be used in a blend of up to 5% with conventional diesel and that 100% use (or 85% blends) of bio-diesel should be restricted to vehicles specifically designed for its use. Given the supply limitations just outlined and the substantial on-cost for vehicles to be compatible with high blend strength or 100% bio diesel, such use should be restricted to captive fleets (also SI ethanol flex fuelled vehicles - FFVs).

Stability of bio-diesel

As noted earlier, use of unmodified vegetable oils results in severe deposit formation and thus use of their esters is preferred.

A number of potential problems have already been found with bio-diesels. Of prime concern is the propensity for the fuel to age. Extensive tests have shown that fuel degradation can take place in the fuel supply chain and in the vehicle fuel system, accelerated by the presence of oxygen, water, heat and impurities. The products of bio-degradation have been shown to cause the following problems-
-*Corrosion of aluminium and zinc components in fuel injection systems due to free methanol*
-*Elastomeric seal failures (softening/swelling or hardening/cracking) due to fatty acids*
-*Low pressure fuel system blockage from fatty acids/free glycerine*
-*Injector spray hole blockage/poor atomisation from potassium/sodium solid compounds*
-*Increased dilution and polymerisation of engine sump oil*
-*lubricity problems polymerisation (thickening) or dilution requiring increased lube oil changes.*
- *Injection pump seizures due to high fuel viscosity at low temperatures*
(Source Delphi Diesel Systems)

Draft CEN standards (prEN14124) are being developed for bio-diesels (publication October 2003?) but until quality standards are established and compliance can be assured for the fuel during storage, manufacturers will be unable to provide a full warranty where such fuel is blended with conventional diesel in blend strengths exceeding 5%.

Availability

It is estimated that availability of land in Europe is such that at best bio-diesel can only provide about 5% of the fuel demands. Thus availability of 100% bio-diesel (B100) would be very limited and perhaps very localised reducing widespread consumer interest in vehicles compatible with such fuel.

Overall

Once fuel quality standards are established and the supply of bio-diesel is assured to remain in conformity with such standards, bio-diesel should form a useful extender to conventional diesel in blends of up to 5% (B5). Supply restrictions and the need for dedicated vehicles will limit widespread use of 100% bio-diesel (B100) in Europe.

Sources include Center for Renewable Energy and Sustainable Energy - USA

9 LANDFILL GAS AND BIOGAS

What Is Landfill gas?

Before defining biogas it is necessary to describe landfill gas which is a major source of biogas, being a cheap, clean and highly efficient source of renewable energy. Landfill gas exploits a resource which could otherwise pollute the atmosphere and transforms it into useful electricity and heat at prices comparable with conventional power. More generation schemes have been built in the UK using landfill gas than with any other "new" renewable technology.

Landfill gas (typically 45% methane, 35% carbon dioxide and 20% nitrogen) occurs naturally wherever household and commercial waste is disposed of in engineered rubbish sites. As the organic matter in the buried waste decomposes it creates a methane-rich **biogas,** the methane providing a valuable source of energy for both heat and power. Landfill gas is produced within about a year of the first tipping. It can continue to be exploited for decades afterwards

Bio gas

Biogas is similar to landfill gas but enriched with methane 60-65% content and minimal nitrogen. At a modern disposal site, excavated areas are progressively lined with an impervious material before being filled with waste and then capped over again. The lining and capping help to prevent gas escaping. The activities of the naturally occurring anaerobic bacteria can be exploited in purpose built biogas plants/digesters to breakdown organic wastes such as liquid manure, fixed muck, waste from agriculture, slaughterhouses and food factories to produce biogas and spent supernatant the latter serving as a high quality liquid agricultural fertilizer. The organic waste material is given to a septic tank or digester, without air or light access. The process duration depends on the special microorganisms (psychophil, mesophil, and thermophil) and their optimal growth temperatures - typically 100, 30 and 10 days at 15º, 35º and 55ºC respectively.

Issues

The developed fermentation gas unfortunately also contains approx. 1% hydrogen sulphide (H_2S) - a poisonous and corrosive gas, which is removed by injecting 3 - 5 % air into the digester or tank separating the H_2 S into water and elementary sulphur, the latter providing liquid manure.

Like wind and solar power, landfill/bio-gas is one of the "new" sources of renewable energy, which have been developed seriously (especially the USA) since the oil price crisis 25 years ago. These gases do not burden the environment, air water or soil, and they conserve fossil resources such as natural gas, oil or coal.

The biogas can be used either directly as a fuel for process heating, electricity generation or it can be further purified and used as an automotive fuel (albeit with a lower methane content than Natural Gas) plus attendant risks related to the presence of potentially corrosive materials. Special lubricants may be required to accommodate the higher sulphur content. A typical engine using biogas would be a reciprocating internal combustion spark ignition engine in the power range of 100 - 2500kW powering generators.

10 OXYGENATES including MTBE (CH_3 $COCH_3$)

What is MTBE?

Methyl Tertiary Butyl Ether (MTBE) is a synthetic chemical commonly used in gasoline since the late 1970s. It is a volatile, flammable, colourless liquid and has a terpene-like odour. MTBE has a relatively high vapour pressure and is water soluble to a significant degree. Originally, MTBE was used as an octane enhancer in amounts up to 3.5 % by volume. More recently, MTBE and other oxygenates were shown to reduce emissions of carbon monoxide and hydrocarbons from vehicles.

How is it made?

MTBE is typically produced in a refinery by mixing a feedstock of isobutylene with methanol. The isobutylene is derived from steam cracking during olefin production and fluid cracking during gasoline production. Table 14 shows various properties of MTBE.

Issues

MTBE is very soluble (50,000 mg/L) but when mixed with gasoline (10% by weight MTBE), the solubility is reduced to 5,000 mg/L. Non-oxygenated gasoline has a solubility of about 120 mg/L.
Small spills and improper disposal are also sources of contamination. Many chemicals in gasoline - including MTBE—can be harmful in water. MTBE is highly soluble and travels faster and farther in water than other gasoline components. MTBE has a strong taste and odour, so even small amounts of MTBE in water can make a water supply distasteful. In most cases where MTBE has been detected, MTBE concentrations are below levels of public health concern. At high levels, MTBE may pose a public health threat.

Commencing in 1981 the U.S. Environmental Protection Agency (EPA) approved the use of up to 10 percent by volume of MTBE and it became a requirement for gasoline to contain 2.7% by weight oxygenate from 1990. Similar provisions were adopted in California from 1996 such that over 95 percent of the gasoline used in that State contained MTBE, in volume concentrations of up to 11 percent. Although the clean fuel regulations did not specify the type of oxygenate required, refineries have most commonly used MTBE as the additive of choice, due to its favourable properties of blending and low cost.
However, leaking storage tanks have been identified as the number one cause of gasoline contamination of ground and surface water in the US and in 1998 EPA established a panel of independent scientists and other experts to examine MTBE's performance in gasoline, its presence in water, and alternatives to its use.
The Panel responded in 1999 by recommending:
• Ensure there is no loss of current air quality benefits from RFG.
• Reduce the use of MTBE, and remove the oxygen requirement in RFG.
• Strengthen the nation's water protection programs, including specific actions to enhance the Underground Storage Tank programs.

However, such concerns are not seen as being a limitation in Europe. The Motor Industry generally sees oxygenates such as ETBE as preferable methods of using bio alcohols.

11 BIOETHANOL - see also Oxygenates

What is Bio ethanol? CH_3CH_2OH (C_2H_5OH)

Ethanol (ethyl alcohol, grain alcohol, EtOH) is ethane with a hydrogen molecule replaced by a hydroxyl radical and is a clear, colourless liquid with a characteristic, agreeable odour. In dilute aqueous solution, it has a somewhat sweet flavour, but in more concentrated solutions it has a burning taste. It is an irritant, hygroscopic and readily absorbed into the skin. Ethanol made from cellulosic biomass materials is called *bioethanol*.

The three largest components of biomass sources (such as trees, grasses, and waste materials) are cellulose, hemicellulose, and lignin. Lignin remains as residual material after the sugars in biomass have been fermented to ethanol. Economic use of this by-product is critical to the financial feasibility of biomass-to-ethanol technology. Lignin (present at 15-30% by wt) can be combusted to provide some of the energy required for the ethanol process but more ambitious use of lignin is planned with a programme under way to develop a process that would convert lignin into fuel additives.

How is it made?

Most ethanol in the USA is derived from grain (often corn) using a process similar to brewing beer where starch crops are converted into sugars, the sugars are fermented into ethanol, and then the ethanol is distilled into its final form. In Europe and other areas ethanol is derived primarily from sugar beet, sugar cane, potatoes etc. In Sweden, ethanol is derived from waste from the timber industry and uses relatively little processing energy.

Monomeric Sugars e.g. sugar cane, sugar beet
The simplest and oldest approach to fuel ethanol production is to use biomass that contains monomeric sugars, which can be fermented directly to ethanol.
Starch e.g. corn
In the United States, today's fuel ethanol is derived almost entirely from the starch contained in corn.
Cellulose
Cellulose, the most common form of carbon in biomass, is (as with starch) a biopolymer of glucose.
Hemicellulose
Yet a fourth form of sugar polymers found in biomass is hemicellulose.

There are four steps in converting biomass to ethanol:
Typically the feedstock passes through a milling process and ground into fine meal which is then mixed with water and alpha-amylase before passing through heaters which liquefy the starch. After cooling, a secondary enzyme, gluco-amylase, is added which converts these liquefied starches to fermentable sugars (dextrose)).

Biocatalysts (micro-organisms including yeast and bacteria) are added to the biomass intermediates to ferment the mash to produce ethanol in a relatively dilute aqueous solution and releasing CO_2 The fermentation product (or beer) contains about 10% alcohol, water and the residue mash (stillage) consisting of non fermentable solid by products. A distillation system then removes this alcohol which reaches 96% strength.

By-products include CO_2 in large quantity, which can be purified and compressed for use in carbonated drinks, or for quick-freeze processes. The protein rich grains from the stillage form a valuable livestock feed. Other by-products include “syrup” which can supplement the grain, and high fructose corn sweetener. The by products can be used to produce other fuels, chemicals, heat and/or electricity. Remaining water is removed and the 200 proof ethanol is denatured (i.e. 2-5% of a product such as gasoline is added) to render the product unfit for human consumption

Benefits

Ethanol is a renewable, domestically produced resource, which reduces air pollution, and in 85% blend with gasoline (E85) it is claimed to show the following advantages over petrol:- 62% lower greenhouse gases and 45% lower VOC. It can be used as a ‘neat fuel’, at high percentages blended with gasoline to overcome some of the problems of its use, or as a blending component in gasoline.

Issues

Normal production vehicles are not compatible with high ethanol content 100% (E100) or 85% (E85) and require special adaptation by the manufacturer. Alcohols suffer from the presence of water (phase separation). The current European Directive allows fuels with up to 5% content of ethanol a level at which current vehicles are compatible. Significant concerns remain over corrosive effects of ethanol/methanol on engine seals, components and paintwork. Some manufacturers are currently investigating methanol as a source of on-vehicle hydrogen.

Market

Brazil already has thousands of vehicles powered by ethanol from sugar-cane plantations. Ethanol can be used as a primary fuel and some countries notably Sweden, Ireland and the U.S are developing a 100% ethanol or E85 (85% ethanol blend) fuel structure for use in flex fuel vehicles but other blends in existence include E10 (10% ethanol blend). Ethanol is the most widely used bio fuel in the US today with more than 1.5 billion gallons added to gasoline each year to improve vehicle performance and reduce air pollution. The US Clean Air Act Amendments of 1990 mandated the sale of oxygenated fuels in areas with unhealthy levels of carbon monoxide. Some auto companies are now selling "flexible-fuel vehicles" that can accommodate both gasoline and ethanol (E85). "Gasohol" (90% gas, 10% ethanol E10) can be used in regular gasoline engines and has achieved some popularity in the US Midwest. In addition, ETBE (an ethanol derivative) is often used in small amounts (around 5%) as an "oxygenate" for cleaner-burning gasoline, used in many major US metropolitan areas

12 METHANOL / BIOMETHANOL – see also Oxygenates

What is methanol (CH_3OH) ?

Methanol (wood alcohol) is an alcohol fuel (a colourless liquid at ambient temperatures and pressures with a pungent odour) that is mainly derived from natural gas in production plants with around 60% total energy efficiency. The ability to produce methanol from non-petroleum feedstocks such as coal or renewable organic cellulosic biomass is of interest for reducing petroleum imports. Methanol can in theory be made from any renewable source containing carbon e.g. refuse, wood pulp, and even seaweed. It can be used as a primary fuel (usually blended with up to 15% gasoline, and known as M85) in vehicles designed or modified for that fuel. Methanol has long been used in racing cars, and is now used in some urban buses. Auto companies withdrew flexible-fuel vehicles that can accommodate both gasoline and methanol (M85) from the market at least 5 years ago following the many corrosion problems experienced.

Although M-85 is the most common form, in future, neat (100%) methanol, known as M-100, may also be used. Methanol is also made into ether, MTBE, which is blended at around 5% with gasoline to enhance octane and to create oxygenated cleaner burning gasoline. Methanol is methane with one hydrogen molecule replaced by a hydroxyl radical (OH) and has chemical properties and physical characteristics similar to ethanol.

How is Methanol Fuel Made?

Although a variety of feed stocks other than natural gas can, and have been used to produce methanol, current economics favour steam reforming of natural gas to create a synthesis gas (carbon monoxide and hydrogen), which is then fed into a reactor vessel in the presence of a catalyst to produce methanol and water vapour. The synthesis gas is fed into another reactor vessel under high temperatures and pressures, where again in the presence of a catalyst; carbon monoxide and hydrogen are combined to produce methanol. The final product is distilled to purify and separate the methanol from the reactor effluent. Most plants supplement their feedstock with purchased carbon dioxide that would otherwise have been released to the atmosphere and this provides an economic use for vast quantities of flared natural gas from offshore oil platforms and other sites. While a large amount of synthesis gas is used to produce methanol, most is used to make ammonia. As a result, methanol plants tend to be near to or part of ammonia plants.

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Benefits

Methanol, has long been known to offer environmental benefits (reduced greenhouse gases), plus economic and consumer benefits having proven its use as a total replacement for gasoline and diesel fuels with all types of vehicle. It is widely used today to produce the oxygenate MTBE added to cleaner burning gasoline. Electric vehicles (EVs) offer hope of displacing petroleum fuels, but current battery technology severely limits performance. Rapid advancement of fuel cell technology promises to provide an Electric Vehicle propulsion unit with the performance of today's cars. The most practical carrier of hydrogen to run these fuel cells is methanol. Many consider that methanol offers the greatest hope for the early and broad introduction of fuel cells to make EVs practical within the next decade by using on-board reformers. Whether reformed to provide hydrogen for fuel cells or used directly as a fuel, methanol promises to overcome the greatest remaining obstacle to widespread use, by offering an economical way to transport and store the hydrogen needed for fuel cells. Methanol fuel cells will greatly reduce carbon dioxide emissions from vehicles and virtually eliminate smog and particulate pollution.

Issues

Cold start problems with methanol favour adding gasoline (e.g. 15% gasoline)
There are serious safety issues associated with methanol.
Methanol burns without a visible flame and is extremely toxic to humans by ingestion or absorption through the skin (it attacks the optic nerve). If ingested (even in minute amounts) it may be fatal and medical attention should be immediately sought.

Methanol Infrastructure and Market

To be successful, an alternative fuel must have a large base of conveniently located fuelling stations. As a practical alternative to conventional fuels, methanol is similar to gasoline, compatible with the existing gasoline service stations, with methanol stations costing about the same. However the US M85 experience suggests that it is difficult to deliver clean fuel to vehicles, due to corrosion problems in the infrastructure. Though liquid, it cannot be moved easily through the existing petroleum infrastructure and in the USA it will probably be transferred between import terminals, production facilities and retail outlets by barge, rail, or truck. In Europe (Rotterdam) there is already a modest dedicated methanol pipeline network based around two of the largest storage tanks in Europe and serving the port area of Rotterdam.

13 DME (sometimes known as DMET), also DOMDME

What is Dimethyl- ether or Dimethoxy-ethane [CH3-O-CH3]

Dimethyl ether (DME or DMET) is a gas at standard temperature and pressure, with a vapour pressure of 4000mm. at 20°C although under modest pressure it is in the liquid state with the appearance of water (it boils at –25.1ºC). It is a synthetic fuel that can be produced from biomass or natural gas in an energy efficient process. The current use for DME is as a propellant in the aerosol industry, replacing HFC's etc. These compounds have very high Cetane numbers, contain oxygen and have very weak carbon to carbon bonds which are believed to aid a more complete combustion and can burn at high efficiency with low emissions and lower greenhouse gas in the very efficient diesel engine process.

An alternative version is Di-oxymethylene dimethyl-ether (DOMDME)

Benefits

To date most research has looked at the application in medium heavy duty engines, where it has been shown to lower NOx and particulates, and could be a promising future fuel for heavier engines in some applications. It is unlikely to see use in light duty vehicles since a shift to hydrogen based transport fuels is envisaged for light duty during the timeframe of any DMM or DME infrastructure development.

Issues

One of the disadvantages of such fuels is that they are volatile, and require fuel systems comparable to liquefied petroleum gas (LPG) e.g. requirement for site area licence as for the use and storage of gasoline and LPG. Pressure vessel containment is therefore required. DME burns without a visible flame (similar to methanol). Different grades exist other than neat. Raw DME is likely to contain some water and methanol due to simplification of the final purification step in its manufacture, on the grounds of cost.

As a liquid it apparently has no lubricating ability and some lubricity additive will therefore be essential if it is to be subjected to conventional high pressure pumping techniques.

Fluorocarbon type elastomers are needed to resist attack but the specification will also have to take into account the possibility of methanol being present
The effect of contact with plastics, metals and surface coatings will need some investigation.

Most DME produced is used as a propellant in aerosols and it is therefore certain that there is considerable knowledge to be accessed within that industry in relation to effects of DME on materials, its storage and management.

14 DMM

What is Dimethoxy-methane? (DMM CH_3-OCH_2-OCH_3)

There is the possibility of using a conjugated version of DME (i.e. larger molecule) called Dimethoxy-methane (**DMM**) – also known as Formal (methylal), a colourless liquid with an odour resembling chloroform, which may have slightly reduced emission benefits but is much closer to the physical properties of liquid diesel fuel at normal temperature and pressure.

Benefits

DMM is the subject of research by some companies as a substitute for conventional Diesel fuel being much closer to the physical properties of liquid diesel fuel at normal temperature and pressure and will potentially offer CO_2 reduction benefits. The cost and emissions implications for using DMM instead of DME have yet to be quantified but the substantial cost of providing a totally new vehicle/engine installation and fuel supply infrastructure might be avoided by taking this route. Provided that exhaust emission levels foreseen for conventional Diesel fuels can be reached using DMM, this fuel could serve as a useful Diesel technology extender. Experimental results at Berkeley (USA) showed an optimal (35%) reduction in PM was achieved with a 30% blend of DMM in conventional diesel accompanied by up to 10% NOx reduction but increased fuel consumption beyond that accounted for by energy densities. PM reductions were highest at high power modes (up to 76% reduction) but at low power there could even be a slight increase in PM.

Issues

DMM may have slightly reduced emission benefits compared with DME, increased fuel consumption, and possibly increased PM at light load (although as noted emissions reductions are substantial at high load).

15 Liquefied Petroleum Gas

What is Liquefied Petroleum Gas (LPG)?

LPG, like natural gas and unlike gasoline, is a comparatively simple mixture of hydrocarbons, propane (C_3H_8 or CH_3-CH_2-CH_3) and propylene (C_3H_6), butane(C_4H_{10}) and butylene (C_4H_8) in various mixtures ranging from 95% propane in some countries to 60% butane in others.

Butane and Propane are odourless, colourless compressed liquefied gases.

Because the stoichiometric air fuel ratio, net calorific value, and latent heat of vaporisation are similar to gasoline, petrol engines can be readily converted with limited modifications. The vehicle, of course, requires a different fuel system.

LPG is produced as a by-product of natural gas processing and petroleum refining and has been used as transport fuel world-wide for over 60 years. The UK has been producing suitably modified vehicles to use LPG for nearly 20 years accounting for over 2/3 of all alternatively fuelled vehicles in the UK today (50000 LPG vehicles). These are predominantly light duty vehicles due to the relative ease and low cost of adapting these engines although applications in the US extend up to medium duty vehicles. There are 1,300,000 such vehicles in Italy, 790,000 in Korea, 530,000 in Australia and 350,000 in the USA – as examples.

Propane generally yields less mpg than gasoline, but per-mile cost is similar.

Vehicles must have special fuel tanks to accommodate this fuel. Despite being widely available in the EC, adoption rates have varied according to fuel taxation measures in each Member State and local government support. The UK market for LPG cars is divided between the OEM solutions and aftermarket conversions. The majority of aftermarket conversions utilise simpler single point or multi point injection technology which confers some benefit over Euro3 petrol vehicles, but less so over Euro4. The best of the OEM solutions using sequential fuel injection exceed Euro4 petrol emissions and still bring significant environmental benefit

How is LPG made?

LPG is a by-product from two sources: natural gas processing and crude oil refining. When natural gas is produced, it contains methane and other light hydrocarbons that are separated in a gas processing plant. Because propane boils at -44 degrees Fahrenheit and ethane boils at -127 degrees Fahrenheit, separation from methane is accomplished by combining increasing pressure and decreasing temperature. The natural gas liquid components recovered during processing include ethane, propane, and butane, as well as heavier hydrocarbons. Propane and butane, along with other gases, are also produced during crude refining as a by-product of the processes that rearrange and/or break down molecular structure to obtain more desirable petroleum compounds.

Benefits

The main environmental benefit of LPG over conventional gasoline engines is a reduction in emissions, up to 30% (NOx), up to 50% (HC) and a modest reduction in CO_2 emissions. Comparisons with a Euro IV gasoline car show 11% reduction in CO_2, 44% reduction in NOx, 19% reduction in total hydrocarbons. Comparing with diesel engines, the main benefit is reduced particulates and NOx. In addition there is reportedly less carbon build-up and the engines are claimed to last two to three times longer than gasoline or diesel engines. The fuel contains almost no benzene, lead or sulphur.

Issues

There are safety issues associated with a) using a gas b) using a fuel that is heavier than air so that there are restrictions on use such as – parking underground, tunnels (e.g. Eurotunnel) ferries. Maintenance of an LPG vehicle needs more care and control than that of a conventional vehicle. LPG is about 20% less dense than gasoline so mileage is correspondingly reduced for a given amount of fuel.

The number of re-fuelling sites has restricted the take-up of LPG in the UK: a situation that will be repeated with the introduction of any new fuel. Currently a bi-fuel (petrol/LPG) vehicle installation is a favoured option given the existing infrastructure of only 1000 refuelling sites in the UK (as at February 14th 2002)

Mono-fuel LPG vehicle installations will bring weight savings and the opportunity for a further reduction in emissions but will require a nationwide network of 1500 or more sites (of the 15000 total) to gain consumer confidence. In the US more than 350,000 vehicles, mostly in fleets such as taxis, school buses, police vehicles, are travelling the nation's highways under propane power. As exhaust emission limits become more stringent, the benefits of LPG, other than a small CO_2 emission reduction, will ultimately (5-10 years) become less significant.

The use of LPG has served and is serving as a useful introduction of alternative fuels to the general public bringing immediate environmental benefits at moderate cost.

16 COMBINATIONS OF FUELS

Bi Fuelled/Dual Fuelled/Mixed Fuel and Flexible Fuelled Vehicles

Bi-fuelled vehicles

Calibrated to run equally on either of two fuels (but not both at the same time) e.g. LPG/gasoline or CNG/gasoline, or hydrogen/gasoline. Typically for LPG or CNG bi-fuelling the engine starts up using gasoline automatically and then switches (manually or automatically) to either LPG or CNG. The vehicle automatically reverts to gasoline if the LPG/CNG runs out but not vice versa.

The person who pays for the fuel will favour using the alternative fuel as much as possible because of the fuel cost saving, but others may prefer to use gasoline if the alternative fuel shows inferior driving characteristics.

Advantages

Bi-fuelling offers the opportunity to introduce LPG or CNG prior to their widespread availability without the danger of the vehicle running empty before a filling station can be reached.
The presence of tanks for both fuels can also be used to extend the range.

Issues

Bi-fuelling inevitably means that a compromise has to be reached between the requirements for the 2 fuels to enable optimisation. This is most significant in the case of CNG / gasoline bi-fuelling, where the high octane number of natural gas would allow increased compression ratio and hence improved efficiency. However, the need to also run on gasoline largely eliminates this potential.

Dual fuelled/Mixed fuel vehicles

Certain vehicles are designed to run continuously on a carefully controlled and continuously varied blend of two fuels each stored on board the vehicle in its own tank. One system being marketed in South America, Middle East etc by a well known US manufacturer uses diesel fuel during idling with progressive increase in the amount of NG introduced as speed increases – up to a maximum of 85% NG. These engines (termed dual fuel engines) are being discussed at ECE WP29 GRPE (Geneva). Although some manufacturers apply the term dual fuel to bi-fuelled vehicles, the term dual-fuel in this report will refer to “mixed” fuel vehicles as described above.

17 NATURAL GAS see also gas to liquid

What is Natural Gas -compressed natural gas (CNG) or liquefied natural gas (LNG)?

Natural gas is a mixture of hydrocarbons—mainly methane (CH_4) a relatively unreactive hydrocarbon — derived from fossil plant deposits and is produced either from gas wells or in conjunction with crude oil production. Natural gas as delivered through the pipeline system also contains hydrocarbons such as ethane and propane; and other gases such as nitrogen, helium, carbon dioxide, hydrogen sulphide, and water vapour. Natural gas is consumed in the residential, commercial, industrial, and utility markets. The interest for natural gas as an alternative fuel stems mainly from its clean burning qualities, its domestic resource base, and its commercial availability to end-users. Also known as methane, the main hydrocarbon present in natural gas, it is referred to as bio-gas when renewably produced from organic waste –see separate section. Large-scale production availability for automotive use has yet to be established in the UK. Sold for storage on board the vehicle either in compressed gaseous form ("CNG" - primarily to fleet operators), or liquid (LNG) form, natural gas has some cost and emissions advantages compared to gasoline, but requires large pressurized cylinders on the vehicle and is more complex to refuel – although LNG can exist at atmospheric pressure at –162ºC. Some CNG models have also been certified as "ultra-low emission vehicles" under stringent California emissions standards. There are 340,000 NG vehicles supported by 340 filling stations in Italy, 75,000 supported by 250 filling stations in Russia and several thousand such vehicles in Europe.

How is Natural Gas Made?

As an example, much natural gas consumed in the United States is domestically produced from reservoirs containing natural gas liquids and other materials, which are processed to separate the gas from petroleum liquids and to remove contaminants. Natural gas is also transported in liquefied form by ship from large gas fields.

Benefits

The clean burning fuel (being predominantly methane in composition such that most HC emissions are methane) has significant environmental and greenhouse gas emissions benefits. Overall CO_2 emissions are generally on a par with diesel engines.

Natural gas is neither corrosive nor toxic, its ignition temperature is high, it is lighter than air, and it has a narrow flammability range, making it an inherently safe fuel compared to other fuel sources. Natural gas cannot contaminate soil or water. It will always rise to the atmosphere out of doors, unlike other fuels, which are heavier than air and can pool either as a liquid or a vapour, upon the ground or down drains. Natural gas contains a distinctive odorant (mercaptan) which allows natural gas to be detected at 0.5% concentration in air, well below levels which can cause drowsiness due to inhalation and well below the weakest concentration which can support combustion. Recent large-scale trials of natural gas vehicles in four cities in Germany showed that they offer a viable alternative to diesel for high-mileage captive fleet applications – e.g. buses, taxis, and vans, according to UBA. About 3,300 CNG vehicles (some adapted) were acquired in Hanover, Augsburg, and two other urban areas. However, whilst CNG buses could meet the latest Euro IV (2005) emissions legislation, retrofitted CNG cars could fail Euro IV HC limits which the equivalent gasoline car would easily meet.

Issues

Lack of infrastructure.

Germany only has currently 2/3 of the 300 filling stations estimated to provide nationwide coverage. In the familiar argument, the fuel industry blames lack of demand and cost for not expanding the fuel supply infrastructure and the vehicle manufacturers say that lack of infrastructure is restricting CNG car demand. To provide a high vehicle mileage range from one tankful, the low energy gas must be liquefied at –162ºC or highly pressurised with a resultant expenditure of energy that reduces the CO_2 benefits

The composition of natural gas can vary significantly from region to region, with methane content ranging from less than 70% to over 95%. These extremes mean that different calibrations may be necessary for different regions or that more complex adaptive systems may be required.

Methane is itself a greenhouse gas with a global warming potential some 32 or 64 times (depending on the measurement time basis) that of CO_2. This therefore reduces, but does not eliminate, the overall benefits in terms of reduced global warming potential arising from the use of natural gas.

Many countries around the world are introducing requirements or incentives to promote NG vehicles.

Currently, Argentina has 686,496 NG vehicles followed by Italy with 370,000, CIS with 210,000, Pakistan 200,000, USA 102,430. Germany has 12,000, Japan 8,884 such vehicles. The UK has 750. *(source NGVA)*

18 GAS TO LIQUID GTL

What is Gas to Liquid GTL

Gas exists in vast reserves in various regions of the globe and is usually flared off as waste at the well head. Gas-to-liquids conversion technologies use chemical or physical means to convert natural gas to a liquid form suitable for ready transport or direct use and offer the potential to use an otherwise wasted resource.

How is it produced

Using chemical GTL technology, the gas could be converted into a petroleum-like liquid that is more easily transported via oil pipeline and tanker to market. Similar GTL conversion processing could be accomplished on offshore platforms or barges (e.g. North Sea or Gulf of Mexico) to facilitate gas and associated oil production from wells that do not have pipeline access.

The conversion is accomplished in one of two ways:

- Compression and refrigeration, in which the gas is liquefied cryogenically and subsequently re-gasified for eventual use; or
- Chemical conversion, in which the gas molecules are chemically altered and combined to form a stable liquid that can be used directly as a transportation fuel or petrochemical feedstock/product.

Benefits

- no sulphur
- ~ 70-80 cetane
- no aromatics
- plants are being built world-wide

Issues

The vast natural gas reserves are often in remote areas which have been without market potential because they are simply too remote from pipelines and urban markets (stranded gas). One option is construction of a gas pipeline from the reserves to all-weather ports for LNG manufacture and export.

Market

Nigeria provides an example of exploiting GTL technology, where the natural gas that would normally be flared off at the well is being converted to liquid fuel, providing a quantity of natural gas equivalent to several percent of the total US demand for natural gas.

Direct chemical conversion of methane to a desirable liquid hydrocarbon has long been a research goal. However, this has so far proven difficult in the quantities and yields required to approach economic feasibility but work continues. There is potential to use a single-step reactor to make the key intermediate product "syngas," which can be readily converted to clean liquid fuels and other hydrocarbons. Syngas is composed of hydrogen and carbon monoxide, and is converted in a separate Fischer-Tropsch reactor to desirable long-chain hydrocarbons. The prospects of this and other conversion process improvements enhance practical options for significant use of GTL fuel products (or blendstock) as a way to reduce air pollution and greenhouse gas motor vehicle emissions through better engine performance, without raising prevailing fuel costs. The chart (appendix - table 19) shows the proportional reduction in emission components using syngas-derived diesel fuel, (from gas and coal feedstock) compared to two other diesel fuels, tested using a 1991 (US) heavy-duty truck diesel engine. Less dramatic but still significant emission improvements have been noted in newer, better performing engines using cleaner conventional fuels, indicating the importance of GTL fuels as a vital fuel option.

19 HYBRIDS (Hybrid electric vehicles)

What Is A Hybrid Electric Vehicle? *Sources include OTT/DOE USA*

When we talk of hybrids, we generally mean hybrid electric vehicles (HEVs). They are nothing new, having been around for 100 years, combining the electric motor (with its clear environmental benefits) with (for example) the internal combustion engine of a conventional vehicle (with its ease of refuelling and extended range capability) resulting in overall improvement in fuel economy and reduced emissions when compared with a purely conventional vehicle.

A hybrid may or may not have an electricity storage system e.g. battery and in the latter case there are charge depleting and charge sustaining varieties, depending on whether the electrical energy stored is topped up by the engine during use. Each pursues quite a different development strategy.

A hybrid may also be series or parallel. In the former case there is one output motor to the transmission (electric motor) which is fed by electricity from either a battery or an ic engine driven generator.

Parallel hybrids have two motors (eg electric motor AND ic engine) each driving the transmission and sharing the work.

The hybrid was conceived to compensate for the inherent limitations in battery technology where current electric vehicles have a range of typically 50 80 miles on one charge – and may need several hours to recharge.

Benefits

When combined with energy saving features such as regenerative braking and use of lightweight materials, the practical benefits of HEVs include improved fuel economy and lower emissions compared to conventional vehicles. The inherent flexibility of HEVs will allow them to be used in a wide range of applications. Although the latest conventional cars have made great gains in terms of efficiency and environmental performance, urban traffic conditions prevent these gains being fully realised in urban use. Hybrids will never be zero-emission vehicles, because of the internal combustion engine, but their use in cities can reduce urban pollution and would cut emissions of global-warming pollutants by a significant amount.

It is argued that engines can be down sized to accommodate average load, not peak load, thereby reducing engine weight. There is a worthwhile increase in fuel efficiency over that of a purely gasoline vehicle – but less so when compared with diesel. Emissions can be greatly decreased (depending on how the vehicle is used).

Types of HEVs

Many configurations are possible for HEVs combining an energy storage system, a power unit, and a vehicle propulsion system. The most common energy storage system is a battery but ultracapacitors, flywheels and other systems are being researched. Power unit options are spark ignition, diesel engines (taxis?), gas turbines (urban buses?) or fuel cells. Propulsion systems are likely to be electric motors but could be direct mechanical drive from the power units.

Overall efficiency will be controlled by the above and by transmission options. A hydrogen fuel cell hybrid, for example, would produce only water as a by-product and run at greater overall efficiency than a battery-electric vehicle that uses wall-plug electricity.

Mybrids (Mild Hybrids)

The battery/electric motor combination in a hybrid operates as a second engine and can represent half the cost of the vehicle. At least one manufacturer has addressed this high cost by offering an alternative in which electric power is confined to powering accessories and supplementing power during hard acceleration thereby substantially reducing battery/electric motor size and costs. The main propulsion unit can also be reduced in size since it can call on up to 30% boost from the electric motor during acceleration. The regenerative braking featured in hybrids is retained.

Issues

Current high cost of technology

20 SOLAR ENERGY

What is Solar Fuel?

Solar energy is already used to power homes and generate electricity. Some research has gone in to evaluating how solar energy may be used to power vehicles but the long-term possibility of operating a vehicle on solar power alone is very slim.

How is Solar Fuel Made?

Photo voltaic cells absorb solar energy from the sun and produce electrical power.

Solar Fuel Market

Possible uses on a vehicle could be solar roof panels to supplement power or run auxiliaries on an electric vehicle. The market for pure solar powered vehicles is very limited and no OEMs will be manufacturing these vehicles.

Benefits

Pure solar energy is 100% renewable and a vehicle run on this fuel emits no emissions although the environmental equation must acknowledge the energy used to produce the photocells. It is claimed that for a given land area of say one acre, the energy conversion of solar cells would be more efficient than growing crops for fuel (BP presentation to SMMT)

LPG case study (for SMMT Future Fuels Strategy Group)

Summary

The 3 key requirements for the successful introduction of a new fuel are:
- Vehicle supply
- Fuel infrastructure
- Clearly demonstrable customer benefits

The vehicle supply and fuel infrastructure factors are inextricably linked as the chicken and egg of this market. Vehicle manufacturers will not supply a vehicle that cannot be re-fuelled, and the fuel companies will not invest in a supply infrastructure until they are confident of selling the fuel.

Clearly demonstrable customer benefits vary depending on the user but are financial in nature. The cleaner emissions benefits of driving an OEM LPG vehicle are not sufficient alone for users to switch to LPG. The main benefits comprise the following factors:
- Fuel cost – fuel duty reduction has resulted in LPG being approximately 50% of the price of conventional petrol. However, with a lower calorific value, the per mile fuel saving is approximately 35%.
- Extra vehicle cost – the Powershift programme currently delivers a rebate of up to 75% of the installation cost for high quality conversions, the environmental benefits of which are proven.
- Customer acceptance. This is a function of time, publicity and the experiences of users as reported through the media. Reliability, durability, safety, acceptable range (>250 miles) and servicing of OEM vehicles issues also need to be taken into account but for OEM product are not major concerns since they are covered by the manufacturers warranty. However, there are concerns that poor quality Aftermarket conversions will result in safety concerns and de-stabilise the LPG market for Aftermarket and OEM products alike.
- Residual value. This is a function of supply and demand and correlates to customer acceptance. Current Residual Values for OEM LPG vehicles equal or in some cases exceed their petrol equivalents.

Vauxhall Vehicle Supply history

Since 1998, Vauxhall has invested more than £2m in a bespoke facility in Millbrook, Bedfordshire where our vehicles are developed and converted to factory specification and come with the same warranty as their petrol equivalents.
In 1999, Vauxhall's plans for 50 LPG sales to local authorities grew to 800 as demand in the public sector developed. These conversions were to the EURO 2 emissions standards and used a Koltec single point injection system.

In 2000, 2395 vehicles were registered as the range of vehicles developed to include 1.6 8v and 16v variants of the Astra and Astravan and 2.0 16v variants of the Vectra and Omega ranges. The market developed beyond depot based fleets and we started selling to higher mileage fleet operators where the fuel savings available made the investment worthwhile.

For 2001, Vauxhall has developed a Koltec gas sequential injection system that exceeds the stringent demands of EURO 4 petrol emissions levels. Initial problems with the development meant delayed deliveries, but full production started in September on Vectra, Astravan and Astra models. The range has expanded to also include the new Combo and should be extended to the 1.6 and 1.8 Zafira in the future. The delay to production has limited deliveries for 2001, with registrations expected to be in the order of 2000 units, but this should be at least doubled in 2002.

Fuel infrastructure

Initially, public access installations were bunkered supplies at depot based fleet operators who were the main customers in the early years. However as the market has developed, more and more sites have become conventional forecourt operations. Public access sites have been being installed at the rate of about 1 per day and should continue at this rate as the market develops.

Demand for the fuel has grown to support both the OEM market and the Aftermarket conversions in response to increased awareness, fuel saving opportunities following the duty reduction measures and customer acceptance.

The following (cumulative) figures track the development of the market.

	No of public access refuelling site	No of vehicles using LPG gas	No of OEM vehicles supplied
At end of 1998	150	3500	
At end of 1999	285	13000	900
At end of 2000	610	39000	3900
At end of 2001	1000	75000	6800
Forecast to end of 2002	1500	120000	14000

Figures provided by LPGA / Vauxhall Motors / LDV

Factors threatening LPG market development

Uncertainty about Powershift programme. Speculation in the press has fuelled fears that the Powershift programme would reduce support levels for LPG powered vehicles which has meant a period of uncertainty and "hold-off" of orders for LPG powered vehicles. Now that support levels have been renewed, it is anticipated that demand will grow, but much ground has been lost and this underlines the importance of the Powershift programme and continued support levels for the introduction of new fuels.

Company car taxation. Whilst the fuel savings from LPG are welcome to the *owner* of the vehicle, under the proposed changes to Benefit in Kind taxation system (from April 2002) the *driver* will not benefit for choosing to run an LPG fuelled vehicle. Despite the 1% discount in the % of list price used for calculation

BIK, and the lower CO_2 value from the alternative fuel, the inclusion of the conversion cost to the P11D value more than offsets this benefit to most drivers. Widescale fleet use is key to the rapid introduction of alternative fuels and Benefit in Kind taxation should be tailored to stimulate switching to alternative fuels.

Safety concerns. The growing market in response to the fuel duty reduction has opened up the market to unregulated Aftermarket conversions. At the same time, the LPGA reports a growing number of poor quality conversions that threatens to compromise the development of the market. Quality standards need to be enforced to ensure that this growing market is not compromised (for Aftermarket and OEM fit alike) by safety scares or accidents resulting from poor quality conversions.

Fuel quality standards. There are concerns that fuel currently in use in the UK may not comply with the EN589 quality standard. The gas sequential injection system used in the best OEM conversions is a complex set-up that requires consistency of high quality fuel in order to operate at maximum efficiency. A fuel standard needs to be agreed and adhered to in all future fuel considerations.

Standardised re-fuelling equipment. The LPG market anticipates problems where three different re-fuelling nozzles have been developed depending on the country of origin. If the same problem is to be prevented in the development of any other future fuel, there needs to be agreement across Europe at an early stage of market development in order to ensure that a common system is used.

APPENDIX

TABLES OF DATA, FUELS SPECIFICATIONS ETC

A useful source for US data on fuels has been the alternative fuels data centre (AFDC) USA which derives much of its information from the American Petroleum Institute

Table 1

Vehicles registered and in use in the UK at 31-12-00 by fuel system

Source SMMT

	Cars		light commercial vehicles		HGVs	Buses coaches
Fuel system	Total in circulation	Registered in 2000	Total in circulation	Registered in 2000	Registered in 2000	Registered in 2000
Petrol	23,803,055	1,922,488	668,045	9452	456	63
Diesel	3,360,454	314,437	2,053,466	232,127	50,908	6,674
Electric	286	49	301	101	5	0
Gas	1,091	52	133	8	31	0
Hybrid - petrol gas	19,653	4,604	1,138	400	12	19
Hybrid - petrol electric	0	0	0	0	0	0
Steam	67	1	9	0	0	0
Compressed Natural Gas	1	1	0	0	0	0
Fuel Cells	0	0	0	0	0	0
Total	27,184,607 all cars	2,241,632 new cars	2,723,092 all LDTs	242,088 new LDTs	51,412 new HGVs	6,756 new bus/coach

Table 2

<u>Possible Timetable For Introduction Of Alternative Fuels/Technologies</u>

Initial applications (shown below) are expected to be cars, buses
Introduction for heavy commercial vehicles will be some way behind

Source SMMT FFSG

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bio-fuels - (as additive)		From 2003																	
Natural Gas (in fleets)	Running now																		
Gas to liquid (as additive)									From 2010										
Petrol Hybrids	Running now and likely to increase																		
Diesel Hybrids		From 2003																	
Hydrogen - Fuel Cells				Limited availability from 2005							General availability from 2012								
Hydrogen - combustion fuel				Limited availability from 2005							General availability from 2012								
LPG	Running now but advantages will diminish																		
Electric	Running now but future use expected to remain limited																		

<u>Biodiesel Properties – Europe</u>

Table 3a

Specific gravity	**0.88**
Viscosity @ 20°C (centistokes)	**7.5**
Cetane Index	**49**
Cold Filter Plugging Point (°C)	**-12**
Net Heating Value (kilojoules per litre)	**33,300**

prEN 14214-2001 FAME table 3b
nb provisional only as at 2001

Property	**Unit**	**Limits**		**Test method**
		minimum	**maximum**	
Ester content	% (m/m)	96,5		prEN 14103
Density at 15 °C	kg/m	860	900	EN ISO 3675 EN ISO 12185
Viscosity at 40 °C	Mm^2/s	3,5	5,0	EN ISO 3104
Flash point	°C	above 101	–	ISO/CD 3679
Sulphur content	mg/kg	–	10	
Carbon residue (on 10 % distillation residue)	% (m/m)	–	0,3	EN ISO 10370
Cetane number		51,0		EN ISO 5165
Sulphated ash content	% (m/m)	–	0,02	ISO 3987
Water content	mg/kg	–	500	EN ISO 12937
Total contamination	mg/kg	–	24	EN 12662
Copper strip corrosion (3 h at 50 °C)	rating	class 1		EN ISO 2160
Thermal stability				
Oxidation stability110 °C	hours	6	–	prEN 14112
Acid value	Mg KOH/g		0,5	prEN 14104
Iodine value			120	prEN 14111
Linolenic acid methyl ester	% (m/m)		12	prEN 14103
Polyunsaturated (minimum 4 double bonds) methyl esters	% (m/m)		1	
Methanol content	% (m/m		0,2	prEN 14110
Monoglyceride content	% (m/m)		0,8	prEN 14105
Diglyceride content	% (m/m)		0,2	prEN 14105
Triglyceride content	% (m/m)		0,2	prEN 14105
Free glycerol	% (m/m)		0,02	prEN 14105 prEN 14106
Total glycerol	% (m/m)		0,25	prEN 14105
Alkaline metals (Na+K)	mg/kg		5	prEN 14108 prEN 14109
Phosphorus content	mg/kg		10	prEN 14107

Table 4

US Biodiesel properties B100

Property	Test Method	SI Units	Typical	Specification
Fuel Description	The US National Biodiesel Board defines biodiesel as the mono alkyl esters of long-chain fatty acids derived from renewable lipid feedstocks, such as vegetable oils or animal fats, for use in compression-ignition engines.			
Acid Number	ASTM D 664	unitless	0.21	0.8 max
Carbon	ASTM D 5291	mass %	77.3	
Carbon Residue	ASTM D4530	mass %		0.05 max
Cloud Point	ASTM D 2500	°C	-1	Report
Cetane Number	ASTM D 613	unitless	47.5	47 min
Copper Strip Corr'	ASTM D130			No 3 max
Density	ASTM D 4052	sp gravity	0.886	
Distillation (IBP)	ASTM D 86	°C	331	
Distillation (10%)	ASTM D 86	°C	333	
Distillation (50%)	ASTM D 86	°C	336	
Distillation (90%)	ASTM D 86	°C	341	360 max ASTM D1160
Distillation (FBP)	ASTM D 86	°C	342	
Glycerin - free	ASTM D6584	% mass		0.02 max
Glycerin - total	ASTM D6584	% mass		0.24 max
Flash Point	ASTM D93	°C		130 min
Heat of Combustion,	ASTM D 240	MJ/kg	39.8	Gross (HHV)
Heat of Combustion,	ASTM D 240	MJ/kg	37.2	Net (LHV)
Hydrogen	ASTM D 5291	mass %	11.8	
Kinematic Viscosity	ASTM D 445	mm^2/s	4.12	1.9-6.0
Pour Point	ASTM D97	°C	-3	
Sulphated Ash	ASTM D 874	mass %	0.001	0.02max
Sulfur	ASTM D5453	% mass		0.05 max
Water and Sediment	ASTM D 1796	volume %	0.02	0.05max ASTM D2709

Although biodiesel B100 can be used , blends of over 20% biodiesel with diesel fuel should be evaluated on a case by case basis until further experience is available.
Source spec US National Biodiesel Board (December 2001),
Other sources OceanAir USA, also report:- "Exhaust Emissions Performance of Diesel Engines with Biodiesel Fuels," C.A. Sharp, Southwest Research Institute, summer 1998

Table 5

Properties and comparisons – Methanol & Ethanol - USA

Source:- Argonne Labs US DOE – Feb 2002

Property	Methanol	Ethanol	Gasoline	E85
Formula	**CH3OH**	**C2H5OH**	**C4 to C12**	
Main constituents	**38C 12H 50O**	**52C 13H 35O**	**85-88C 12-15H**	**57C 13H 30O**
Octane(RON + MON)/2	**100**	**98-100**	**86-94**	**96**
Lower heating Btu/lb	**8570**	**11500**	**18000-19000**	**12500**
Gallon (US) equiv	**X 1.8**	**X 1.5**	**1**	**X 1.4**
Mpg vs gasoline	**55%**	**70%**	**100%**	**72%**
Reid Vapor Pressure	**4.6**	**2.3**	**8-15**	**6-12**
Ignition Point **% fuel in air** **Temperature ºF**	 **7-36** **800**	 **3-19** **850**	 **1-8** **495**	
Specific Gravity	**0.796**	**0.794**	**0.72-0.78**	**0.78**
Cold weather start	**poor**	**poor**	**good**	**good**
Vehicle power	**+ 4%**	**+5%**	**0**	**+3-5%**
Stoichiometric ratio	**6.45**	**9**	**14.7**	**10**
Other properties *Various sources*				
Molecular Weight	32.1	46.1		
Boiling Point ºC	64	78		
Freezing Point ºC	97.7	-114		
Vapour Pressure at20C	96mm Hg	46mm Hg		
Flash Point ºC	11.1	12.7		

Table 6

Typical Properties Of DMM and DME (fuel grade) – *drawn from various sources*

Physical Properties	**DME**	**Typical: EN590**	**DMM**
Normal fuel related:			
Density kg/m^3 (liquid form?)	660-668	840	860
Specific Gravity	1.59		
Cetane Number	>55	49	50
Calorific Value (min.) MJ/kg	27.6	42.5	27.6
Lower heating value MJ/kg	28.43		
Viscosity mm^2/sec	?low?	2.5	
Melting Point °C	-141		-105
Boiling Point °C	-24.9	180 – 370	41.7-44
Auto-ignition Temperature °C	236 to 350	250	
Flash Point ºC			-18
Lubricity µm $WSD_{1.4}$	∞	300 – 400	better than DME
Other useful data:			
Vapour Pressure	4000mm @ 20°C	>760mm @25°C	330mm
Vapour Density	1.62		3.6
Stoichiometric a/f ratio	9.0	14.6	
Heat of Evaporation kJ/kg	460 @ -20°	250	??410 @ 20°
Explosion Limits (%gas in air)	3.4 – 18.0	0.6 – 6.5	
Composition %m/m, carbon	52.0	86.0	
hydrogen	13.0	14.0	
oxygen	34.8	0	42.1

The DME Cetane no. is claimed to be 55-60, but the determination method is not revealed so it is assumed calculated i.e. cetane index.

Table 7

European Gasoline

Property	Units	E U 2000 EN228	E U 2005
RVP summer	Kpa	60	
Olefins	% v/v	18	
Aromatics	% v/v	42	35
Benzene	% v/v	1	
Oxygen	% m/m	2.3	
Sulphur	Ppm	150	50
Octane	RON	95	
Octane	MON	85	
E100	% v/v	46	
E150	% v/v	75	

Table 8

Typical commercial properties of liquefied petroleum gas		
	Commercial Butane C_4H_{10}	**Commercial Propane C_3H_8**
Relative density of liquid at 15 ºC	**0,57 to 0,58**	**0,50 to 0,51**
Specific Gravity gaseous phase at 17.5ºC		**1.5**
Imperial gallons/ton at 15 ºC	**385 to 393**	**439 to 448**
Litre/tonne at 15 ºC	**1 723 to 1 760**	**1 965 to 2 019**
Relative density of gas compared with air at 15ºC and 1 013,25 mbar	**1,90 to 2,10**	**1,40 to 1,55**
Volume of gas (litres) per kg of liquid at 15ºC and 1 013,25 mbar	**406 to 431**	**537 to 543**
Volume of gas (ft^3) per lb of liquid at 60ºF and 30 in Hg	**6,5 to 6,9**	**8,5 to 8,7**
Boiling point at atmospheric pressure ºC approx.	**-2**	**-45**
Vapour pressure for products at their maximum specified vapour pressure (gauge): Temp. ºC -40 -18 0 15 38 45	**Bar - - 0,9 1,93 4,83 5,86**	**Bar 0,5 2,3 4,5 6,9 14,5 17,6**
Latent heat of vaporisation (kJ/kg) at 15 ºC	**372,2**	**358,2**
Latent heat of vaporisation (Btu/lb) at 60º F	**160**	**154**
Specific heat of liquid at 15ºC (kJ/kg ºC)	**2,386**	**2,512**
Sulphur content per cent weight	**Negligible to 0,02**	**Negligibleto 0,02**
Limits of flammability (percentage by volume of gas in a gas-air mixture to form a combustible mixture)	**Upper 9,0 Lower 1,8**	**Upper 10,0 Lower 2,2**
Calorific Values: Gross: (MJ/m^3) dry (Btu/ft^3) dry (MJ/kg) (Btu/lb) Nett: (MJ/m^3) dry (Btu/ft^3) dry (MJ/kg) (Btu/lb)	** 121,8 3 270 49,3 21 200 112,9 3 030 45,8 19 700**	** 93,1 2 500 50,0 21 500 86,1 2 310 46,3 19 900**
Air required for combustion (m^3 to burn 1 m^3 of gas)	**30**	**24**
Octane RON	**100**	**100**
Flash Point		**-104ºC**
Flame temperature in air		**3595ºF**

Propane data based on information from American Petroleum Institute (Alcohols & Ethers pub) also e-lpg.com et al

Butane data from various sources inc e-lpg.com

Table 9
Natural Gas Vehicle Quick Reference Fuel Guide
Source:- Natural Fuels Co Inc USA

Fuel and Primary or Typical Composition	Net or Lower Heating Value (Energy available for power)*	Factor: Gallons required for same mileage as gasoline
Unleaded Regular Gasoline (C8H15-18)	114,000 BTU / Gallon (liquid)	1.00
Natural Gas (CH4)	114,000 BTU / Equivalent Gallon	1.00
Liquefied Natural Gas (CH4)	76,000 BTU /Gallon (liquid)	1.50
Diesel(C16H34)	128,000 BTU /Gallon (liquid)	0.89
Propane(HD5) (C3H8)	82,450 BTU /Gallon (liquid)	1.38
Methanol (CH3OH) M85 (85% methanol, 15% gasoline)	57,000 BTU / Gal. (liquid) 65,500 BTU / Gal. M85 (liquid)	2.00 1.74

- A Kilowatt-hour is 3413 BTUs.

US Conversion factors: 1 Gallon Gasoline Equivalent=

- 6.3 lbs. Or 129 cubic feet natural gas
- 1.38 gallons propane
- 2 gallons methanol (1.74 gallons M85)

Table 10
Fuel Characteristics

	Natural Gas	**Ethanol**	**Gasoline**	**Methanol**	**Propane**	**Diesel**
Toxic to Skin	**no**	**slight**	**moderate**	**moderate to high**	**no**	**moderate**
Toxic to lungs	**no**	**slight**	**moderate**	**moderate**	**no**	**moderate**
Specific gravity: lighter or heavier than air (air=1.00)	**0.55 (lighter)**	**1.59**	**3.4**	**1.11**	**1.52**	**>4.0**
Auto-ignition temp, °F (Temp req'd for spontaneous ignition)	**1200**	**867**	**500**	**793**	**920**	**500**
Limits of flammability, % volume in air: Lower %	**5.3**	**3.3**	**1.0**	**5.5**	**2.0**	**0.5**
Upper %	**15.0**	**19.0**	**7.6**	**44.0**	**9.5**	**4.1**
Luminous flame	**yes**	**faint**	**yes**	**no**	**yes**	**yes**
Source / feedstock	**natural gas**	**grain, biomass**	**petroleum**	**natural gas, other hydro-carbons**	**petroleum, natural gas**	**petroleum**

Table 11

Comparisons of energy content, methane/CO_2 emissions etc)

Fuel	Petrol	ULSD	Ethanol	DME	LNG	CNG	LPG	H2	Elect
Net energy content MJ/kg	43.9	43				47.6	46.4	12.0	
Octane RON			110	>55	130	130	100		
Typical storage density kg/l	0.738	0.830				0.143	0.508		
Pressure bar					5	200			
Temperature ºC					-162	Amb't			
Energy content MJ/litre	32.4	35.7				6.81	23.6		
Tank vol vs diesel #			x 1.7	x 2.5	x 2.5	x 6	x 2		
Tank wt vs diesel #			x 1.7	x 2.1	X 2	x 5	x 2		
Non vehicle CO_2 base *	10.3	7.5				6.75	7.6	83.7	145.1
Non vehicle CO_2future*	10.5	7.5				6.3	7.6	81	122.3
Non vehicle CH_4 base *	0.016	0.015				0.048	0.017	0.085	0.422
Non vehicle CH_4future*	0.016	0.015				0.042	0.017	0.044	0.088

* Units gms/MJ # for same range Ref Cleaner Fuels for Europe Helsinki 2000 in part

Table 12

<u>Reformulated diesel and synthetic diesel fuels Shell Fischer-Tropsch</u>

Fuel Property	Test Method	SI Units	Shell Fischer Tropsch	
Density	ASTM D 1298	sp gravity	0.7845	Also ASTM D4052
API Gravity	ASTM D 287	degree API	54	
Distillation (ibp)	ASTM D 86	°C	210	
Distillation (10%)	ASTM D 86	°C	260	
Distillation (50%)	ASTM D 86	°C	300	
Distillation (90%)	ASTM D 86	°C	331	
Distillation (fbp)	ASTM D 86	°C	338	
Kinematic Viscosity	ASTM D 445	mm^2/s	3.57	
Cetane Index	ASTM D 976	unitless	> 74	above max measurement capability
Carbon	ASTM D 5291	mass %	84.91	
Hydrogen	ASTM D 5291	mass %	14.97	
Nitrogen	ASTM D 5291	mass %	0.67	
Sulphur	ASTM D 5453	ppm	< 5	below min measurement capability
Sulphur	ASTM D 129	mass %	< 0.05	
Olefins	ASTM D 1319	volume %	0.1	
Saturates	ASTM D 1319	volume %	99.8	
Aromatics	ASTM D 1319	volume %	0.1	
Total Aromatics	ASTM D 5186	mass %	0.3	
Monoaromatics	ASTM D 5186	mass %	0.1	
Polyaromatics	ASTM D 5186	mass %	0.2	
Water/Sediment	ASTM D 1796	volume %	< 0.02	
Ash	ASTM D 482	mass %	< 0.001	
Ramsbottom Carbon	ASTM D 524	mass %	0.02	
Copper Corrosion	ASTM D 130		1A	
Heat of Combustion,	ASTM D 240	MJ/kg	47.1	gross (HHV)
Heat of Combustion,	ASTM D 240	MJ/kg	43.9	net (LHV)
Flash Point	ASTM D 93	°C	72	
Cloud Point	ASTM D 2500	°C	3	
Lubricity	ASTM D 6078	g	1700	(SLBOCLE)
Lubricity (HFRR)	ASTM D 6079	mm	0.51	average of 3 tests
Gum Content	ASTM D 381	mg/100 ml	0.2	(unwashed)

Ref SAE Report No. 982526, 'Emissions from Trucks Using Fischer-Tropsch Diesel Fuel,' P. Norton et al

This Fischer-Tropsch diesel fuel was obtained from Shell's middle distillate plant. This plant reforms natural gas with pure oxygen to generate synthesis gas. The synthesis gas is then converted through a catalysis process into liquid hydrocarbon fuels.

Table 13

MTBE typical properties

Molecular Structure	**$CH_3OC(CH_3)_3$**
Molecular Weight	**88.14 g/mole**
Density	**0.741 g/ml at 20deg C**
Vapour pressure	**313 Torr at 30 deg C**
Freezing Point	**-108.6 deg C**
Boiling Point	**55.2 deg C**
Solubility in Water	**4.8% at 20 deg C**
Oxygen Content	**18.2%**
Energy Content	**93.5 MTBU/gallon**
Henry's Law Constant at 25 deg C	**0.022**

Table 14
Fuel Parameter Values (USA - national basis)

Property	**Conventional Gasoline**		**Gasohol**	**Oxyfuel 2.7% wt O_2**	**RFG phase 1**
units	**Average**	**Range**	**Average**	**Average**	**Average**
RVP psi Summer	**8.7**	**6.9-15.1**	**9.7**	**8.7**	**7.2-8.1**
RVP psi winter	**11.5**		**11.5**	**11.5**	**11.5**
T50 ºF	**207**	**141-251**	**202**	**205**	**202**
T90 ºF	**332**	**286-369**	**316**	**318**	**316**
Aromatics vol%	**28.6**	**6.1-52.2**	**23.9**	**25.8**	**23.4**
Olefins vol%	**10.8**	**0.4-29.9**	**8.7**	**8.5**	**8.2**
Benzene vol%	**1.6**	**0.1-5.18**	**1.6**	**1.6**	**1.0 1.3max**
Sulphur ppm	**338**	**10-1170**	**305**	**313**	**302 500max**
MTBE vol%	**-**	**0.1-13.8**	**-**	**15**	**11 (7.8-15)**
EtOH vol%	**-**	**0.1-10.4**	**10**	**7.7**	**5.7 (4.3-10)**

Table 15
WATER AND FUEL EMULSION French specification
Source Lubrizol

CARACTERISTIQUES	METHODES	UNITES	Limites	
			Minimum	maximum
Corrosion Lame de cuivre (3 h – 50°C)	pr NFM 07-098	SD	Classe 1	
Stabilité par Centrifugation à la livraison: % à 5 min pente 5-15 : (% à 15-% à 5)/10	pr NFM 07-101	% (v/v) % (v/v)/min	0,3	9
Teneur en eau (y)	pr NFM 07-104	% (m/m)	9	15
Teneur en soufre	pr NFM 07-100	mg/kg		=[**S***(100-y)]/100
Viscosité cinématique à 40°C	pr NFM 07-097	mm^2/s	2,50	7,00
Masse volumique à 15°C	pr NFM 07-096	kg/m^3	835	870
Température Limite de Filtrabilité	pr NFM 07-099	°C		Eté : 0 Hiver : -15
Pouvoir lubrifiant, diamètre de marque d'usure corrigée (wsd 1,4) à 60 °C	pr NFM 07-103	µm		460
Point d'éclair Cleveland	pr NFM 07-102	°C	70	

Table 16
GTL emissions comparisons
using a US 1991 HDDE
source fossil.energy.gov (US DOE)

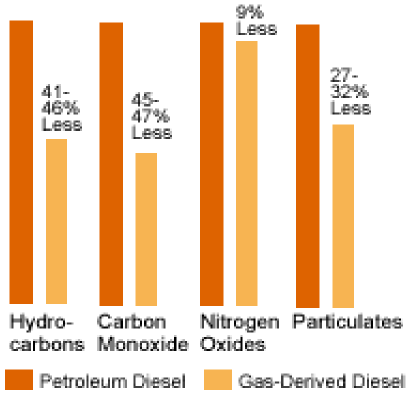

Table 17
Example of well to wheel analysis – source R Espino et al (1998) –
subject to much debate and not necessarily endorsed by FFSG but included for illustrative purposes to show comparison approach for different fuels needed in the future

Fuel	Production to mfr	Reforming	Fuel Cell	Net Efficiency
Gasoline	0.85-0.90	0.75-0.83	0.45-0.50	0.29-0.37
Methanol	0.67-0.71	0.78-0.85	0.50-0.55	0.26-0.33
Hydrogen 350bar	0.63-0.72		0.55-0.60	0.35-0.43

Table 18 Gas properties

Source e-cats.com data book (Industrial Gas Data Book)

Gas		Molecular wt	Specific gravity Water=1	Specific heat kj/kgºC	Boiling Point ºC	Specific gravity air=1	Specific heat kj/kgºC	Density kg/m3
			Liquid phase			Gaseous phase		
Hydrogen	H2	2.02	0.071	9.668	-252.8	0.07	14.34	0.0899
Oxygen	02	32	1.14	1.669	-183	1.113	0.9191	1.429
Methane	CH4	16.04	0.425	3.481	-161.5	0.559	2.207	0.717
Ethane	C2H6	30.07	0.546		-88.63	1.056	1.715	1.3566
Propane	C3H8	44.1	0.58		-42.04	1.573	1.625	2.02
Methanol	CH3OH	32.04	0.795	2.533	148.2	-	0.3274	0.089

Table 19 Examples of Types Of Fuel Cell

Source fuel cells 2000

Type Of Fuel Cell	Operating Temperature	Availability	Application
Alkaline	150-200 ºC	Very expensive and not yet commercial	300W-5kW has long been used by NASA. Possible use in hydrogen powered vehicles
Direct methanol fuel cell	50-100ºC	Military use some problems to be resolved	Tiny-mid size portable eg cellphones and laptops
Molten (lithium) carbonate fuel cell	650ºC		10kW-2MW - electric utilities and other large applications
Phosphoric acid fuel cell	150-200 ºC	Commercially available now but not competitive in UK	Large size low power favours use in stationary apps but may find use in large vehicles eg buses
Proton exchange membrane fuel cell also known as solid polymer	50-90 ºC	Not yet commercial	High power density suited for smaller stationary, also light duty mobile uses (favoured by car companies)
Protonic ceramic fuel cells	700 ºC	Being researched	
Regenerative or reversible fuel cells		Being researched	
Solid oxide fuel cell	1000 ºC	Close to commercialisation	High power 100kW/cell industrial and electricity generation but also perhaps automotive use
Zinc air fuel cells			High specific energy being tested with EVs

SMMT FUTURE FUELS STRATEGY GROUP

All UK vehicle producers were represented in the SMMT Future Fuels Strategy Group

The group identified:

- **the major motor vehicle fuel alternatives**
- **the advantages and disadvantages of each fuel**
- **the most promising long-term fuel for 2020 and beyond**
- **the government support required**

The group proposed:

- **an introduction strategy**
- **any intermediate 'stepping stones'**
- **a body of industry experts to help develop a national strategy**

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