# Energy efficient cars

## New fuels, new cars, new technologies

Price 40p

### Some history

Most people agree the first true car was built by the German Carl Benz in 1885. Steam power had been tried but steam engines are innately inflexible as well as heavy. Though Benz's car had 3 not 4 wheels it was powered by the new, easily handled, liquid called petrol in the relatively new 'internal combustion engine'.

Early motor cars resembled the horse drawn coaches they replaced with large wheels and rudimentary suspensions. They were considered unpredictable and, in the UK, had to be preceded by a man with a flag to warn of their approach. This ceased in 1896 with the passing of the Locomotives on Highways Act, an event marked by the first London to Brighton rally in November of that year.

Initially there were no garages with mechanics or pumps with petrol but progress was rapid. By 1905 cars were recognisable as the forerunners of those today with headlamps, bonnets, windscreens, rubber tyres and number plates. Model T Fords rolled off the first assembly line in 1909 in America. The age of cheap mass production and affordable motoring had begun.

UK citizens own over 25 million cars today (there are almost 3 million more vans, lorries, etc.) with over 2.5 million new cars sold in 2004. Market forces have encouraged huge R+D expenditure which has made cars more attractive, cleaner and efficient. Emissions of noxious exhaust gases such as the nitrogen oxides are barely 2% of levels in 1970. Engine efficiency doubled in the USA in the same period. The average new car sold in the UK does 10% more mpg than one bought in 1998. Affordable motoring has brought huge benefits to individuals and families. People can do more, see more and enjoy more. In many ways cars are the ideal form of transport, capable of travelling door to door in comfort, when and where required, with luggage. But there are downsides and this note deals with the most compelling: the increased dumping of carbon dioxide ($CO_2$) to the atmosphere and how it might be reduced.

It is still possible to make cars more efficient, and different engines and different fuels are coming on the market. The options will be explored one by one.

### More efficient cars

Until recently virtually all cars used the 'internal combustion' engine with petrol the dominant fuel although this is now challenged by diesel. Conceptually the internal combustion engine is very simple. A crankshaft is turned by pistons pushed down inside cylinders. A mix of fuel and air is drawn in through valves at the top of the cylinders. The valves close, the fuel/air mix lit and is burnt explosively pushing the pistons down. Other valves open and the burnt gases expelled. A sparking plug is used to light the fuel in a petrol engine which operates most efficiently at about 3000 revs/min. At that speed each piston in a 4 cylinder engine will fire 25 times a second.

When more fuel is put in (for example when accelerating) or the engine is turning faster, the spark must occur earlier so that all the fuel can be burnt, and the converse is true. Much very clever engineering goes into engine management systems to ensure that the right amount of fuel enters each cylinder at the optimum time over as wide a range of revolutions and engine situations as possible. Furthermore gears are used so that engines can run as close to their optimum speeds as possible over a large range of road speeds. Even so the best petrol engines use only about 25% of the fuel energy and diesel only about 35%, most of the rest being lost in heat. Previously 'automatics' had fewer gears and were less efficient, but this has changed.

Engines do 4 things: accelerate the car, overcome friction in the moving parts, push the air in front out of the way,

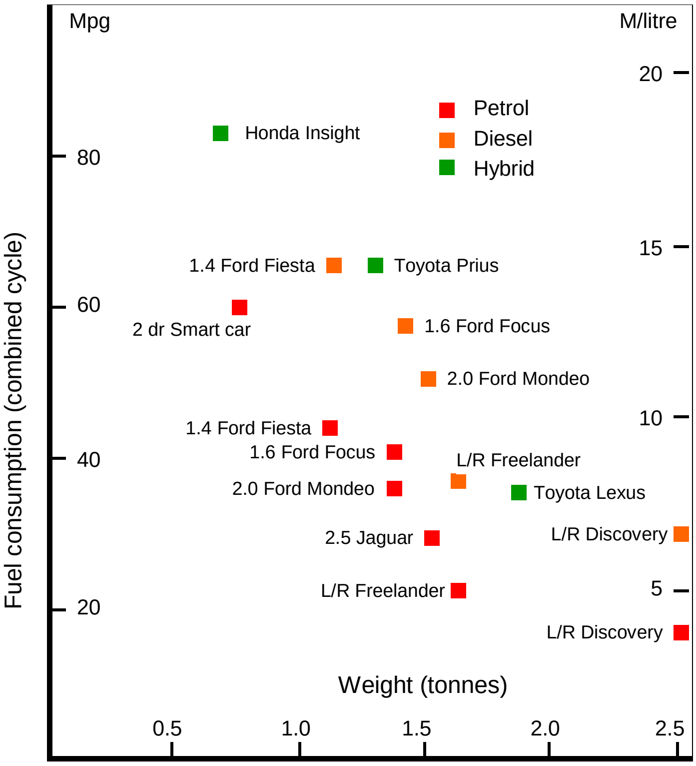


*Fig. 1 Weight v fuel efficiency, 11 Ford + 4 other cars*

and power items like lights, wipers and air conditioning. Great advances have been made over many years in the quality of manufacture and design to reduce friction and air

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resistance. Modern cars look similar, for example with rounded bonnets and swept back windscreens, because this is a simple way to reduce air resistance.

Energy efficiency demands cars be as light as possible (see Fig. 1). Engineers have used plastics instead of steel in body panels and aluminium in engines. Unhappily, safety demands strength which adds weight and requires seat belts, anchorages, child seats and so on, and more and more accessories like air conditioning are being fitted. Lightness demands cars be small. Some small cars have amazing amounts of space and the percentage of families choosing small cars rose from 27 to 34% in the 10 years to 2004. Unhappily families buying so called 'Chelsea tractors' almost tripled, from 4.5 to 11.9%, in the same period. Weight generally has risen. The BMW 'Mini' weighs twice as much as the Issigonis original. Weight is critical. Broadly speaking if one doubles the weight of a car one doubles its fuel consumption and $CO_2$ emissions. Fig 1 shows that a petrol Ford Fiesta weighs just over 1 tonne and does 10 miles/litre whereas a petrol Land Rover Discovery weighs about 2 1/2 tonnes and does 4.

## Alternative fuels

The most common fuels have the general formula $C_nH_{2(n+1)}$. Methane ('natural' gas), propane and octane have the formulas $CH_4$, $C_3H_8$ and $C_8H_{18}$ respectively. When burnt, the carbon converts to $CO_2$ and the hydrogen to water, both reactions releasing energy. Petrol is usually a blend of fuels from this family with between 5 and 12 carbon atoms. LPG (liquefied petroleum gas) is a mix of propane and butane ($C_3H_8$ and $C_4H_{10}$). The more hydrogen to carbon atoms, the more energy is released per unit of fuel so, in theory, methane should be better than petrol. It is. Unfortunately whereas petrol is liquid at normal temperatures and can be carried around in a tank, methane is a gas and has to be stored, supplied and transported under pressure. This adds weight as well as complexity to the design. Liquefied or compressed natural gas (LNG or CNG) is used principally in heavier vehicles like buses where weight and space are less critical. LPG requires less pressure to make it liquid and has been successfully used in cars. It emits about 10% less $CO_2$ per mile than petrol. All the above alternatives (and also hydrogen) can be used in internal combustion engines but none overcomes the inherent inefficiency of that type of engine.

There are 2 other chemical families used for fuel: alcohols and esters. Methanol (methylated spirit or 'meths') and ethanol (the alcohol one consumes in beer and other drinks) have the formulas $CH_3OH$ and $C_2H_5OH$ respectively. Industrial ethanol used to be sold under the Cleveland Discol label as an alternative to petrol. Diesel is basically an ester and has a formula something like $C_{19}H_{36}O_2$. Diesel engines operate at higher temperatures and pressures than petrol ones and so are more efficient. They emit some 11% more $CO_2$ per gallon but that gallon goes almost 50% further!

One exciting development is that ethanol can be obtained from crops, most commonly sugar cane or beet, and can and is being blended with petrol or, in some cases, replacing it entirely. Similarly oil from all kinds of crops such as oil seed rape can be blended with diesel. At one time it was thought that the amount of energy extracted from the crop barely exceeded that needed to grow, harvest and process it so there was no net gain in $CO_2$ emissions. Practices have improved however and, especially if the waste products are burnt for heat or electricity, one can reach a position where only 20% of the energy obtained is required for growing and processing the crop[1]. Bio-fuels are already on sale. Large areas of land are needed, far more than is likely to be available for the UK to be self sufficient in the foreseeable future, but they offer a simple, proven way to reduce transport's $CO_2$ emissions in the short term.

## Alternative engines

Rover developed a turbine powered car but the engine wasn't flexible enough to cope with urban traffic conditions. Mazda have studied the Wankel rotary engine for many years though it is a smoother running rather than more efficient internal combustion engine. Current research is concentrating on electric motors whose efficiency is 50 to 80% compared to 25% for petrol. Moreover electric motors are efficient over a full range of speeds so do not need a gear box.  Why then do they not dominate the market?

The answer lies not in the engine but the 'fuel'. Until recently electricity had to be 'carried around' in batteries which are heavy even for a limited range. Worse, batteries usually take electricity from the mains where it is rarely available at more than 33% efficiency. Thus the gains in efficiency *within* the car are lost generating the electricity in the first place. Though electric cars emit no $CO_2$ this is not saved, just displaced.

An alternative is to generate the electricity in the car from the fuel 'on board'. This is why there is so much interest in the fuel 'cell'. A fuel cell takes hydrogen and combines it with oxygen in air to produce electricity and water. The electricity powers electric motors. Trials of buses using hydrogen to power fuel cells have been undertaken and it is clear the technology, if not the economics, can work. However the fundamental problem - getting the fuel in the first place - remains. Hydrogen needs to be produced from *surplus* non fossil sources. If not there is no environmental point using it. Iceland is one of very few countries that could benefit. It has surplus hydro electric and geothermal resources and could produce hydrogen by electrolysis from these sources.

There is another possible option. The problem with wind (and solar) energy is that it is unreliable. This will limit how much can be supplied to the grid unless some way can be found to 'dump' or offload surplus electricity at times of high wind and supplement it at times of low wind. The surplus energy could be used to produce hydrogen and, if not wanted for the grid, used for transport.

Hydrogen can be obtained in other ways than electrolysis. One route is from methane which can be converted to hydrogen and $CO_2$. Though this might seem a backward step, using the hydrogen to run a fuel cell and power an electric motor is more efficient than using methane directly in a 'petrol' engine. It is particularly attractive where the methane is produced from biomass plants such as landfill sites or sewage sludge digestion.

Several manufacturers are testing cars using hydrogen, the most exotic probably being the 745h version of the BMW 7 series vehicles. These run on liquid hydrogen which has to be cooled (and kept cool) at –253$^{o}$C, a technically exacting requirement. An alternative route is to store the hydrogen chemically and several options here are being explored[2].

## Hybrids

There is another ingenious, albeit limited, route which is currently attracting great publicity. As explained above the internal combustion engine is inefficient when running above or below an optimum speed and also when not working flat out. Honda and Toyota are leading the way in adding electric motors and batteries to some of their models. This arrangement creates 4 options. First the battery can be recharged via a charger assisting the braking, though this does not produce much electricity on long runs. Second the engine can charge the battery when the car is cruising and the engine is ‘under employed’. Third the electric motor can *assist* the engine when the car needs it, for example when accelerating. Fourth the electric motor can be used when the car is starting from rest when the engine is least efficient. (The engine can even be switched off for example at traffic lights.)

The consequence is that smaller engines can be used and fuel efficiency raised, though the gains whilst cruising on motorways are not so good as those in ‘stop start’ motoring in urban areas. The most publicised ‘hybrids’ are the Toyota Prius, and Toyota Lexus purchased by David Cameron. Honda produced the smaller engined Insight but is now concentrating on a Civic hybrid. Ford have the Escape. Other models are being planned.

Once again, however, we should not be carried away. The Prius emits 104 grams/km of $CO_2$, does 14.4 miles/litre, reaches 60 mph in 11.5 secs, but generates a maximum torque (pulling power) of only 115 Newton metres (Nm) which limits its peak acceleration and towing power. The Ford Fiesta 1.4 diesel emits only a little more $CO_2$ (114 grams/km), does the same miles/litre and, though it takes longer to reach 60 mph (16.2 secs), has 40% more torque (see Fig 1). Nor is the Prius cheap. Though it saves on the weight and cost of a large engine, it carries weight penalties for its battery, electric motor and extra electronic management systems, and some of its fuel efficiency savings are being challenged. Furthermore a replacement battery will cost £1200 or more, though it should last 8 years or half the lifetime of the car.

In fact petrol/electric hybrids are not much more efficient in energy use than existing diesels, and the case for the Lexus is very poor. It is a big car weighing almost 2 tonnes, and emits far more $CO_2$ (186 grams/km) than most family cars. Despite this we have the absurd situation that the Lexus is free from London’s congestion charge.

What would make a much more significant difference would be the development of *diesel*/electric hybrids. These too are coming. Wrightbus is providing 6 Electrocity diesel/electric hybrid buses for trials in London and the French, who have an excellent track record developing diesels, are designing hybrid Peugeot 307s and Citroen C4s. Commercial launches are thought to still be 4 years away but there is talk of consumptions rising to 83 mpg for reasonably sized cars.

## Conclusions

There are 3. First, the development of a growing market in bio-fuels is a virtual win-win. It does mean increasing agricultural productivity even further however, possibly through GM technology, in order to release as much land as possible to grow fuel crops. The government is close to announcing that it wants 5% of all transport fuel to be ‘bio’ by April 2008 by imposing a Renewable Transport Fuel Obligation (RTFO) for that date.

Second any owner looking to purchase a new car should be advised to buy the *lightest* one possible and then either a diesel or a hybrid.

Third, Government, if it is genuinely keen to reduce $CO_2$ emissions from transport, should increase the cost of *fuel* as fast as possible. This is the most direct way to reduce $CO_2$ emissions. Engineers will design for what the market wants and ultimately consumers are sensitive to price. Higher petrol prices do not preclude congestion charges at selected places and times. Nor do they exclude schemes to give discounts on the first, say, 500 litres of fuel/year, for essential use[3].

Today there is a ferment of new ideas in the engineering world and it is not clear which technology will win through. In the short term there is obvious potential to use a *diesel* electric hybrid. In the long term it still seems the future lies with electric traction but it is not certain whether cars using fuel cells or batteries will succeed. The fuel cell route is the more technically demanding and it would help if an economic means of storing hydrogen chemically ‘on board’ could be found as this would avoid the need for the extremely high pressure or low temperature systems otherwise needed. The battery route is simpler but depends on making the breakthrough to improve the range/weight ratio of the battery which has so far proved elusive. With either however we have to find non fossil routes (over and above those needed for electricity and heat) to produce the fuel. A great deal of research is required for this as well.

*More detailed information on bio-fuels, hydrogen and transport generally can be found in the following ALDES briefing notes:*


1. *Biofuels for Transport*
2. *Hydrogen: The clean fuel for the future?*
3. *The Transport Dilemma*