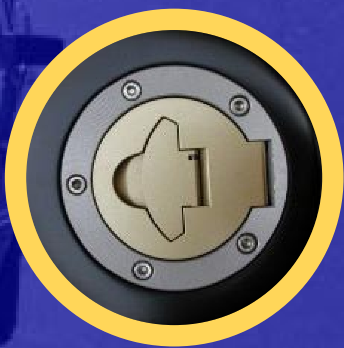
The future of road vehicle fuels – forecasts to 2020

2008 edition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The future of road vehicle fuels – forecasts to 2020

2008 edition

January 2008

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Introduction

The purpose of this report is to examine the currently-available fuels for road vehicle propulsion – the gases, liquid hydrocarbons and their alternatives – and their likely future, out to a horizon of 2020.

In theory, any substance which is transformed while taking part in an exothermic chemical reaction can be regarded as a fuel. The resulting heat may be used directly for warmth, or it may be used to drive some kind of machine (a 'heat engine'), or it can create a power output by some other means, as in a fuel cell.

Many chemical reactions are exothermic (often violently so) and many elements and compounds could be regarded as fuels in the general sense. From a practical point of view however, the only fuels available in huge quantity, and which are easily exploited alone or in combination, are carbon and hydrogen, which combine with airborne oxygen to form new compounds and release heat. In doing so, they form easily-dispersed and non-toxic oxides, respectively carbon dioxide (CO_2) and water (H_2O).

Carbon, in the form of wood, later of charcoal and coal, has been a fuel since time immemorial. From the 19th century it was joined by the hydrocarbons, combinations of hydrogen and carbon. Because of the way carbon and hydrogen form their chemical bonds, the number of hydrocarbon compounds is almost countless. Many of them, however, must be treated with care. Not only are the lighter liquid hydrocarbons, including petrol, highly volatile and capable of forming explosive mixtures; they are also, to various degrees, toxic if drunk or inhaled. Some, such as benzene, have also been shown to be carcinogenic. Users of hydrocarbon fuels, and the designers of fuel systems, need to guard against these drawbacks. Hydrocarbon fuels may take the form either of gases – naturally occurring, or as a by-product of turning coal into coke – or liquids, derived by refining naturally-occurring crude oil, or by other means.

Coal, crude oil and natural gas are so-called 'fossil fuels'. These were, in effect, sequestered beneath the earth's surface many millions of years ago when environmental conditions were very different and encouraged the lush growth of vegetation and organisms. Then, as the vegetation and organisms died, they were laid down as deposits that were transformed by pressure, temperature and time until they assumed their present forms. In effect, when conditions were favourable, nature created a vast store of energy out of organic materials which had themselves ‘fed’ on solar radiation.

Since their first appearance, the vast majority of self-propelled road-going vehicles have depended on internal combustion engines, the alternatives of external combustion (the steam engine) and of battery-electric propulsion having been examined in the early 20th century and found wanting. The vast majority of internal combustion engines burn liquid hydrocarbon fuels, refined from ‘fossil’ crude oil.

The inevitability of exhaustion…

The impossibility of this situation continuing more or less indefinitely seems first to have been acknowledged during the 1970s, when rapidly-increasing fuel production and consumption led to concerns about how long the reserves of crude oil would last, and what might happen when they were effectively exhausted. It became customary to measure the remaining reserves in years, a figure arrived at by dividing the quantity of proven, economically-recoverable reserves by the annual rate of production – the so-called R/P ratio. It is important to bear in mind, when considering this ratio, that R refers to *“those quantities that geological and engineering information indicates with reasonable certainly can be recovered from known reservoirs under existing economic and operating conditions”.*[1] It is by no means the amount of crude oil remaining underground worldwide.

In practice, the R/P ratio has remained close to 40 years since before 1990. It rose to a high of 43 years in 1992 (a year of economic slowdown, especially in the former USSR), fell just below 40 years in 2000, but stood at just over 40 years at the end of 2006.[2] The equivalent current figures for natural gas and coal are currently around 60 years and 200 years respectively.

Although new oilfields continue to be discovered as existing ones are depleted, the near-stationary R/P ratio is also a consequence of economics. Rising demand, coupled with political turmoil and economic uncertainty, had already

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[1] *BP Statistical Review*, 2007

[2] Ibid

driven up the cost of crude, over US$90/barrel at the time of writing, although some of this apparent increase was due to the recent weakness of the US dollar. The trend of increasing prices seems bound to continue – though unevenly – at a rate determined both by the relationship between supply and demand, and by political and economic circumstance. Whenever the price rises, expensive techniques such as very deep drilling, the use of new technologies to wring more output from depleted fields, or the processing of oil shales and tar sands, become more economic relative to that price, extending the 'proven' reserves.

Studies carried out by the US Geological Survey and others have concluded that likely total reserves including the technically-difficult and expensive 'frontier' sources of crude oil – the estimated ultimate recovery (EUR) – stand at between three and six times the amount extracted since the process began. Given such figures, it is clear that crude oil is by no means going to be exhausted by 2020, in other words, within the period covered by this report. However, nobody suggests that extraction can continue indefinitely. The supply of crude oil is vast, but evidently not inexhaustible.

…and concern about global warming

In the 1990s a second concern arose, and grew to overshadow the question of long-term supply. This took the form of anxiety about global warming which (in the opinion of the majority of climatologists and environmental scientists) was being caused by the growing rate of CO_2 emission, the direct result of extracting and burning increasing quantities of fossil fuel containing carbon. Beyond the turn of the century, this second concern has become increasingly widely felt and expressed.

From the late 1960s onwards, concern had also began to be expressed about the noxious emissions of internal-combustion engines – the unburned hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NOx), and later also the particulate matter (PM) emitted by diesel engines. These anxieties led to the introduction of emission control measures that are legally enforced by governments. Such measures have been highly effective, and a typical 2008 road vehicle emits about one-hundredth the level of noxious emissions produced by a 'pre-control' vehicle of the mid-1960s. In other words, the noxious emissions have been effectively controlled, although the legal requirements continue to tighten.

By contrast, nothing similar can be done to control the emission of 'greenhouse' CO_2, whose quantity is directly proportional to the amount of fuel burned – or more accurately, to its carbon content. The only possible measures for control or alleviation are:

- to use fuels with a lower fossil carbon content;
- to reduce fuel consumption through improved vehicle efficiency;
- to take measures to discourage the extent of vehicle use; and
- to capture and store the emerging CO_2 (sequestration).

Of these measures, the first calls for changes in fuel technology and is therefore a main subject of this report. The second is already being addressed, though with varying enthusiasm in different markets. The third is politically highly sensitive and likely to be successful only on a limited scale. The fourth – sequestration – is much more difficult to achieve in a moving vehicle than in a fixed-base emitter like a power station, and is unlikely ever to be relevant to the vehicle fuels situation.

Compared with the 'greenhouse threat', the threat posed by noxious emissions from vehicles controlled to 2008 levels (Euro IV and V, US Federal SULEV) now seems barely significant except perhaps in urban areas suffering from chronic traffic congestion. They are, in any case a separate consideration, and are not addressed in this report.

It must be stressed at the outset that these are all areas in which opinions are never unanimous, or evidence wholly conclusive. There is still a small minority body of opinion which contends that the present (and undeniable) global warming trend is part of a natural cycle to which man-made CO_2 emissions make a barely-significant difference. Equally, and contrary to the consensus, it is sometimes argued that as-yet undiscovered oil reserves will extend the R/P ratio well beyond 40 years. By the same token, there are those who argue that the only way to preserve acceptable air quality is to achieve the ideal of a 'zero emissions' vehicle (ZEV).

While recognising the existence of such views, this report broadly reflects the majority opinion in these three areas, which are:

- global warming is a matter of serious concern which needs to be urgently addressed;

- crude oil reserves are finite to the extent that by the middle of the 21st century, scarcity will have driven prices to the point where alternatives will become essential; and
- when currently-contemplated (noxious) exhaust emission limits have been achieved, the technical emphasis will have to shift to improved efficiency and lower fuel consumption in order to minimise CO_2 emissions.

The key questions

Any attempt to map the future of vehicle fuels must be centred on the answers to a handful of key questions, namely:

- How much fuel will be needed for the vehicle fleet of the future?
- How much fuel is, and will be available to meet this need?
- How urgent is the need to counter the threat of global warming?
- What means are available to enable us to counter this threat (and by implication, also to counter the threat of crude oil exhaustion), and how quickly can such means be introduced?
- What overall conclusions can be drawn from the answers to the preceding questions?

These questions are considered in Chapters 1, 2, 3, 4 and 5 respectively. Chapter 4 therefore includes (in particular) discussion of the biofuels which may enable road vehicles to continue operating entirely within the short-term carbon cycle, without adding to the greenhouse effect through the further use of fossil carbon, while Chapter 5 discusses the speed with which such fuels may replace the fossil fuels in vehicle use.

Chapter 1 Present and future fuel needs

Current patterns of fuel use

Conventionally, the overall market for fuels is divided into four sectors: transport, industrial, power generation and residential/commercial (in effect, mainly heating and air conditioning). Industrial, commercial and residential users are essentially 'fixed base' – that is, their power needs can be met by an electrical supply (although currently, a high proportion of their heating requirement is provided by natural gas). Electric power generation systems can run on any type of fuel, or indeed from any 'sustainable' power source – solar, wind, tidal, wave power, geothermal or hydro-electric – or from nuclear fission. Examining all the options for that purpose would require a parallel report, and one of far greater complexity.

Road vehicles are another matter altogether. Except for a relative handful of vehicles – namely trams and trolley-buses – which pick up electric power on the move, road vehicles must carry their power source with them. That power source ideally needs to provide the maximum amount of energy in relation to its weight and bulk, and to be easily replenished when it is close to exhaustion. This has always been the appeal of the liquid hydrocarbons, which contain large amounts of chemical energy per unit weight and volume, can be distributed and dispensed through piping systems with low energy consumption and low losses, stored at ambient temperature and pressure in relatively-simple, low-cost tanks, and easily dispensed at a high energy-transfer rate.

The alternatives to liquid fuels are compressed gases and electric power. The gases are clearly inferior in terms of energy content per unit volume. To be at all useful they must be highly compressed – with xxx bar of pressure widely accepted, and up to xxx bar suggested – but such pressures bring with them their own problems of safe handling and storage, and substantially-increased costs. In addition, the cycle of pressurisation and depressurisation itself involves a significant energy loss. Electric power, for its part, may be stored on board a vehicle in a battery or (for a short time) in capacitors. However, batteries are greatly inferior to liquid fuels in terms of energy stored by unit

Chapter 2 Present and future vehicle fuel supplies

Energy for mobility

As was explained in Chapter 1, vehicles are unique in their need for fuels that are compatible with mobility. With very few exceptions, vehicles must carry their energy source on board, and that source should therefore provide the highest practical energy density while at the same time being reasonably safe. It should also be easy to handle at every level of the distribution infrastructure from large-scale production down to vehicle replenishment. Liquid fuels best fulfil these requirements, although gases and stored electrical energy are alternatives in vehicles where limited range and slower replenishment can be accepted.

The fuels offered to consumers today (2008) include:

- petrol, refined from crude oil;
- diesel fuel, refined from crude oil;
- ‘synthetic’ petrol or diesel, derived from coal or natural gas;
- ‘biofuels’, ethanol (petrol substitute) or fatty-acid methyl esters (FAME – diesel substitute) derived from sustainable and natural waste products;
- Gases, including liquefied petroleum gas (LPG) and compressed natural gas (CNG); and
- electrical energy stored in batteries.

Of these, the crude oil derivatives are universally available in large volume. LPG is an established fuel. The synthetics and biofuels, although already available in increasing volume, are essentially ‘fuels of the future’, together with CNG and, looking further ahead, liquefied natural gas (LNG) and pure hydrogen. Electrical energy is a special case, since it has been universally available for more than a century but has never achieved more than ‘niche’ vehicle applications.

Within this chapter, we examine the current availability of each of these existing options and the likely ability of producers to ramp up their output to meet the levels of demand set out in Chapter 1. The long-term prospects for

Chapter 3 Global warming – the urgency

As noted in the Introduction, the 1990s saw one fuel-related anxiety replaced by another. Fears about the effects of crude oil exhaustion gave way to fears about the effects of global warming caused by man-made emissions of CO_2, as a result of the continued large-scale burning of fossil carbon and hydrocarbon fuels.

The challenge: real or imaginary?

It is well beyond the scope of this report to conduct an exhaustive examination of the available evidence for man-made causation of global warming, the mechanisms via which increased concentrations of CO_2 result in warming, or the risk of that warming reaching a 'tipping point', beyond which the situation could not be reversed merely by reducing emissions to some previous level.

For the purposes of this report, it is sufficient to note that the considerable, perhaps overwhelming majority of scientific opinion is that global warming is a very real threat. If there is any remaining disagreement, it concerns the speed of the effect and the imminence of very real damage. The overall situation was summed up by Sir Nicholas Stern at the very outset of his exhaustive report[7]: *"There is now clear scientific evidence that emissions from economic activity, particularly the burning of fossil fuels for energy, are causing changes to the Earth's climate."* The bulk of the *Stern Review* is devoted to economic mechanisms (such as carbon trading) via which the trend of increasing CO_2 emissions could be encouraged to reverse, although Chapter 3 provides a detailed overview of the possible global effect of adverse climate change.

The essence of the counter-arguments, which are still advanced, is that current trends in atmospheric temperatures are part of a long-term cycle and that by comparison with naturally-occurring emissions, the man-made contribution remains small. It is not disputed by any reputable scientist that atmospheric temperatures increased during the 20th century, and continue to

[7] Nicholas Stern, *The Economics of Climate Change*, Cambridge University Press, 2007

Chapter 4 Global warming – the counter-strategies

In our introduction, we listed the four ways in which global warming resulting from vehicle CO_2 emissions might be countered:

- using fuels with a lower fossil carbon content;
- reducing fuel consumption through improved vehicle efficiency;
- taking measures to discourage the extent of vehicle use; and
- capturing and storing the emerging CO_2 (sequestration).

Before proceeding to technical considerations, it is worth considering the option of measures intended to reduce the volume of private vehicle use and a switch to public transport, either fiscally (via road pricing) or by actual prohibition, perhaps according to time and area. In the Introduction, we observed that all such measures would be *"politically highly sensitive and likely to be successful only on a limited scale"*. Almost all past experience shows that motorists are prepared to make seemingly remarkable sacrifices – in other words, to pay handsomely – to retain the freedom, comfort, relative security, flexibility and convenience of their own cars. Motoring is already a major revenue-raiser for governments; it seems likely that fiscal measures would raise even more revenue but have relatively little effect on CO_2 emissions. Outright prohibition is unlikely to be seen as being politically feasible.

It was also observed in the Introduction that the sequestration (capture and storage) of CO_2 is much more difficult to achieve in a moving vehicle than in a fixed-base high-volume CO_2 emitter like a power station, and is unlikely ever to be relevant to the vehicle fuels situation. This is not to say it cannot be a highly significant technology for fixed-base emitters, however.

Thus, it seems that moves to reduce CO_2 emission by road transport must depend on the remaining two strategies, namely the widespread adoption of fuels which contain less fossil carbon and preferably none at all, and continued efforts on many technical fronts to improve vehicle operating efficiency and thus reduce fuel consumption.