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**SELECT COMMITTEE ON
SCIENCE AND TECHNOLOGY**

**TOWARDS ZERO EMISSIONS FOR
ROAD TRANSPORT**

REPORT

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SELECT COMMITTEE ON
SCIENCE AND TECHNOLOGY

TOWARDS ZERO EMISSIONS FOR
ROAD TRANSPORT

REPORT

Presented to the House of Lords

LONDON: THE STA. JOSEPH OFFICE

2000

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REFERENCES IN THE TEXT ARE AS FOLLOWS:

- (Q) refers to a Question in oral evidence
 (p) refers to a paper in HL Paper 117-I of Session 1995-96

FIRST REPORT

13 November 1996

By the Select Committee appointed to consider Science and Technology.

ORDERED TO REPORT

TOWARDS ZERO EMISSIONS FOR ROAD TRANSPORT

CALL FOR EVIDENCE

The Committee issued as its Call for Evidence:

The House of Lords Science and Technology Committee has appointed Sub-Committee II, under the chairmanship of Lord Dixon-Smith, to conduct an enquiry into the future of road transportation and the prospects for achieving sustainability. We will receive evidence in writing and in person, with a view to making a report to the House of Lords later in 1996.

The Sub-Committee invites written submissions on matters of relevance to this topic, but in particular on the questions listed below. The enquiry will focus on improvements to the internal combustion engine and alternatives to it in the context of road transport (including biofuels, batteries, fuel cells, compressed natural gas and hybrid power systems). The Sub-Committee will also examine the role of the United Kingdom science and industrial base in the development, production and exploitation of this technology.

The Sub-Committee is well aware that major reductions in transport-related pollution can be achieved through reduced reliance on private motor vehicles and through other changes in social attitudes. It is **not** our intention to examine these aspects of the problem. The car and road transport are here to stay, and they have brought many benefits. So we pose the question: can we reduce their adverse environmental effects and are developments in this field taking place with sufficient rapidity?

1. What is the current state of technology with regard to achieving fuel efficiency and lower emissions from internal combustion engines? What prospects are there for the future and what are the barriers to the widespread application of this technology?
2. What progress has been made towards achieving technological and economic viability for alternatives to the internal combustion engine as a power source for road transportation?
3. On balance, would these technologies have a positive environmental effect (in particular on reducing air pollution) or would they just change the nature and location of pollution?
4. How safe are the competing technologies?
5. How is research into new technologies being co-ordinated on national and international levels, and with what focus? (For example on standardisation to ensure that only one refuelling/recharging infrastructure is required.)
6. What impacts have the following had on research and development into alternative power technology in the United Kingdom: the "Realising Our Potential" White Paper (1993), the Technology Foresight Exercise; the change in ownership of the Transport Research Laboratory; the privatisation of the electricity industry; the planned break-up of British Gas; and new emissions regulations set by the European Union?
7. What is the United Kingdom's capability for research and development in the basic supporting sciences of electrochemistry, electromechanics and materials?

8. What is the industrial capacity for exploitation and production in the United Kingdom, and how is industry positioned to take advantage of export potential to countries where regulations and/or public demand have already created markets for low emission vehicles?
9. Should steps, including fiscal instruments and subsidies, be taken to force the pace of technological development and public demand for more fuel efficient and less polluting forms of road vehicle?
10. What are the prospects for developing cheap and flexible low emission power sources for road vehicles in developing countries and for countries where there is still potential for massive increase in vehicle ownership and usage?

ACKNOWLEDGEMENTS

The enquiry was based on the assistance of a wide range of individuals and organisations (listed in Appendix 3), and the Committee is grateful for their generosity and expertise. We would like to thank in particular Ford Motor Company Ltd for arranging a visit to their Research and Engineering Centre at Dunton and demonstrating their Ecostar electric vehicle, and the Natural Gas Vehicle Association and Johnson Matthey for organising interesting and informative visits. The Foreign and Commonwealth Office provided information and assisted in the organisation of the Committee's visit to Germany, and we are particularly grateful to those we met there.

CHAPTER 1 INTRODUCTION

1.1 Transport is an emotive issue. Cars especially provoke strong reactions from those affected by them and, in the developed world, cars affect all of us. All sides agree on the importance of road transport, but for different and often conflicting reasons. For some, cars are a vital instrument of economic growth, a passport to personal freedom and the ultimate consumer good. For others, they are a dangerous, highly polluting luxury which the planet cannot afford. These two ideas coexist uneasily together in society. There is a degree of truth in the saying that "Most people are worried about the problems caused by other people's cars".

1.2 Road vehicles have had an immense impact on our way of life. The development of road transport has been one of the driving forces behind the enormous improvement in the standard of life over the last one hundred years. Cars have brought about a revolution in personal mobility, especially for the elderly and those in rural areas, and all forms of road transport are essential for the working of a successful economy. The motor vehicle and road fuel industries are themselves vital components of most modern economies. It is the success of the road vehicle which has led to many of its problems.

1.3 Accidents causing death and injury are the most visible damage caused by road vehicles. Although the number of fatalities from road accidents is declining in the United Kingdom, it is increasing in most parts of the developing world¹. Other matters are perhaps less visible but are becoming increasingly significant. Congestion is a serious problem, and road transport infrastructures take up considerable amounts of land. Noise pollution from road vehicles has only recently become the subject of academic study². Road vehicles also contribute to air pollution and to the carbon dioxide emissions which it is feared are leading to global warming.

1.4 The number of vehicles on roads and the distance travelled by them continues to rise all over the world. In the United Kingdom the last thirty years have seen a 250 per cent increase in road traffic, and it is predicted that in the next thirty years there will be an increase of between 58 and 92 per cent³. In the future road traffic growth in the developing world will outstrip that in the developed countries. This growth will spread further the immense benefits—and the drawbacks—associated with road vehicles.

1.5 In the last few years, the speed of technological change in the field of vehicle technology appears to have been comparable with the growth in the number of vehicles. There have been many developments since this Committee first addressed the question of electric vehicles in 1980⁴. In this Report we concentrate on different propulsion unit technologies, including both the internal combustion engine and alternatives to it. Our principal concern during the enquiry was to examine whether technology will be able to maintain the benefits of road vehicles while reducing their adverse effects, particularly in relation to the problems of air pollution and fuel consumption (leading to the emission of carbon dioxide).

1.6 The enquiry did not consider every aspect of road transport and therefore limits its conclusions to those aspects of the problem on which it took evidence. Issues such as improving traffic flows (through telematics or road building), or of switching from cars to bicycles and trains, may be important elements of an overall transport strategy, but they lay outside the scope of the

¹ HL Deb 22 April 1996 col. 34 and World Health Organisation, *Investing in Health Research and Development* (September 1996).

² See for example H. Ising et al., *Subjective Work Noise—A Major Risk Factor in Myocardial Infarction*. (Paper presented at Internoise Conference 1996.)

³ Department of the Environment/Scottish Office, *United Kingdom National Air Quality Strategy* (August 1996), p 45; Department of the Environment, *Indicators of Sustainable Development for the United Kingdom* (March 1996), p 32.

⁴ 1st Report (1979–80), *Electric Vehicles* (HL 352).

enquiry⁵. As the Report concentrates on technology aimed at reducing air pollution and emissions of carbon dioxide, the following sections examine air pollution and carbon dioxide emissions from road vehicles. It is important to emphasise that these are two separate problems, and that solving one will not necessarily be beneficial for the other.

AIR POLLUTION

1.7 The use of motor vehicles introduces into the atmosphere a wide range of substances which are known to have adverse effects on human and animal health, vegetation and buildings. Most of the pollution is caused by emissions from the exhausts of vehicles, but a substantial fraction is caused by evaporative losses from individual fuel tanks, evaporation and spillage during refuelling, and during the transport and refining of petrol and diesel. The pollutants which currently cause the most concern are oxides of nitrogen (NO_x), unburnt hydrocarbons, particulate matter (PM), volatile organic compounds (VOCs)⁶, sulphur dioxide (SO₂) and carbon monoxide (CO). Some of these pollutants lead to the formation of low-level ozone, which is also a pollutant. Box 1 gives some background information on the health and other effects of pollutants emitted by road vehicles.

1.8 The air pollution caused by road vehicles is most serious in urban areas, where there are high concentrations of both vehicles and people. Some of the pollutants can, however, cause problems over a wider area. For example, ozone can take hours to form from other pollutants and several days to disperse. Some of the highest concentrations of ozone are found in rural areas where photochemical reactions have had time to occur in polluted air dispersing from urban and industrial centres. Similarly, acid rain is a regional rather than a local problem, and emissions can easily cross national boundaries. It has been estimated that the total cost in health terms of emissions of air pollutants attributable to transport may be equivalent to 0.3 to 0.4 per cent of European Union Gross Domestic Product⁷.

CARBON DIOXIDE EMISSIONS

1.9 Carbon dioxide (CO₂) is not considered to be an *air pollutant* in the usual sense as it does not cause ill-health in humans at usual ambient concentrations. However, in recent years there has been increasing concern over the amount of material that mankind is introducing into the atmosphere which inhibits the radiation of energy from the earth out into space. It is feared that this is causing and will continue to cause an increase in global temperatures. The United Kingdom Government consider that:

“Unless urgent action is taken, the global temperature is predicted to rise by 2°C by 2100. Climate change will have adverse effects on human health, on terrestrial and aquatic ecological systems, and on social and economic life”⁸.

The Government are committed to reducing emissions of global warming gases.

1.10 The principal global warming gases are CO₂, methane and nitrous oxide. It is the level of CO₂ in the atmosphere which is most affected by human activity. Global atmospheric levels of CO₂ have been increasing since the 18th century, and the rate of increase is itself increasing. One of the major sources of CO₂ is the road vehicle, which is powered by the combustion of hydrocarbon fuels. These fuels are a combination of carbon and hydrogen and when they are burnt in oxygen, as in a car engine, CO₂ is created. The only way to reduce CO₂ emissions is to reduce fuel consumption.

⁵ The Royal Commission on Environmental Pollution conducted a wide-ranging enquiry on *Transport and the Environment* in 1994 (18th Report), which gives an excellent overview of the subject.

⁶ The House of Commons Environment Committee conducted a detailed enquiry on VOCs in 1995: 1st Report (1994–95), *Volatile Organic Compounds* (HC 39).

⁷ European Community Document 6022/96, *Car of Tomorrow Action Plan* (SEC(96)501), p 3.

⁸ *Transport—The Way Forward* (Cm 3234), p 22. See also *Climate Change—The UK Programme* (Cm 2427) (1994) and Intergovernmental Panel on Climate Change, Contribution of Working Groups I and II to the Second Assessment Report (both 1995).

BOX 1—HEALTH EFFECTS OF AIR POLLUTANTS EMITTED BY ROAD VEHICLES

Nitrogen oxides (NO_x)—Oxides of nitrogen are formed at the very high temperatures created in the combustion chamber and are linked to the exacerbation of respiratory diseases.

Hydrocarbons—Hydrocarbons are emitted when small amounts of the fuel used in internal combustion engines pass through the combustion chamber unburnt or only partially burnt. Some of the material takes the form of small particles (see below), and some is classed as volatile organic compounds (VOCs). The presence of these and also NO_x in the atmosphere can lead to the formation of low-level ozone (see below). Some of the VOCs emitted, including benzene and 1,3 butadiene, are known carcinogens.

Ozone (O₃)—Low-level ozone is formed by the reaction of several different substances in sunlight (particularly NO_x and VOCs). If present in the air in high concentrations it "has an irritant effect on the delicate surface tissues of the body" and can cause coughs, eye and throat irritations and headaches (p 26). It also causes damage to crops and buildings. One witness noted that ozone "is the major pollutant cause of crop loss throughout Europe" (p 382).

Carbon monoxide (CO)—Produced during the combustion process, it reduces the oxygen-carrying capacity of the blood and can in extreme cases cause death. In the concentrations found in cities, it may cause illness in individuals with certain forms of heart disease.

Lead—Lead is probably the best known of the pollutants emitted by road vehicles. It accumulates in organs such as the brain and in nervous tissue with serious effects on the nervous system, haemoglobin synthesis and haemopoiesis.

Sulphur—Sulphur dioxide is created during the combustion process from the sulphur which is present in small quantities in mineral oil and can cause respiratory problems. It also contributes to acid rain, which damages flora, fauna and buildings. Sulphur can also form particulate matter.

Particulate matter (PM)—The generic term given to very small particles present in the atmosphere. Recent research indicates that episodes of high atmospheric PM concentrations correlate to increases in asthma attacks and deaths from respiratory illnesses. Particles are commonly measured as "PM10"; the mass of all particles less than 10 microns in diameter (1 millionth of a metre). Diesel vehicles emit far more particulate matter than petrol vehicles by mass, but there is uncertainty as to whether it is the mass of particles or their size or chemical composition which is the most important factor in determining the level of danger. Both petrol and diesel engines emit ultra fine particles (less than 0.1 microns in diameter) consisting mainly of carbon compounds and acid salts. Particles up to 2.5 microns in diameter are respirable and may lodge deep in the lung, causing a significant health risk.

Cocktail effect—There is therefore uncertainty about the exact mechanisms by which some of these pollutants cause ill health in humans. Professor Anthony Seaton, Chairman of the Expert Panel on Air Quality Standards, stated that the possible synergistic effects of these pollutants was an important, though poorly understood issue (Q 463).

Sources: Evidence from Professor Seaton (QQ 460–495), Professor Anderson (p 267), the Natural Environment Research Council (pp 381–385) and the Department of the Environment (pp 25–28). The reports of the Expert Panel on Air Quality Standards, the Quality of Urban Air Review Group and the Committee on the Medical Effects of Airborne Pollutants. Parliamentary Office of Science and Technology, *Particles and Health*, Report no. 82, June 1996.

1.11 It is important to emphasise that road transport is not the sole man-made source of air pollutants or of CO₂. Table 1 estimates the amount of pollutants and CO₂ emitted by the road transport, domestic and industrial sectors of the United Kingdom economy in 1970 and 1993. Table 2 divides up the road transport sector into the different classes of road vehicles, and gives an estimate of the contribution of each class of vehicle to urban emissions of PM10 and NOx.

TRENDS IN EMISSIONS

1.12 It is clear from Table 1 that between 1970 and 1993 road transport in the United Kingdom increased its emissions of pollutants and CO₂, while the establishment of smokeless zones and other measures reduced emissions in many sectors. The rise is largely attributable to the continuing growth in road traffic. This growth in emissions was mirrored throughout the rest of the developed world, and unless there is an effective response it will also become increasingly true in developing countries where the number of road vehicles is growing rapidly.

Table 1—Emissions of black smoke, NOx, CO and CO₂ from the road transport, domestic and industrial sectors in the United Kingdom

	Road Transport		Domestic		Industry		Total
	tt ⁽¹⁾	% of total	tt	% of total	tt	% of total	
<i>Black smoke⁽²⁾</i>							
Emissions in 1970	101	10	786	76	63	6	1028
Emissions in 1993	229	52	134	30	23	5	444
<i>Oxides of nitrogen</i>							
Emissions in 1970	647	28	427	18	734	32	2322
Emissions in 1993	1208	51	283	12	384	16	2347
<i>Carbon monoxide</i>							
Emissions in 1970	2835	62	1196	26	191	4	4539
Emissions in 1993	5141	91	295	5	81	1	5641
<i>Carbon dioxide</i>							
Emissions in 1970	18,000	10	53,000	29	77,000	43	181,000
Emissions in 1993	34,000	22	42,000	28	43,000	28	151,000

(1) Figures given in thousand tonnes.

(2) Black smoke is an older measure which is very roughly equivalent to PM, measuring the opacity of smoke rather than the mass of particles composing the smoke, and extrapolating a figure from that measurement.

Note: The sum of the three sectors listed does not equal the total as there are other sectors responsible for emissions which are not shown.

Source: Department of the Environment, *Digest of Environmental Statistics No.17* (1995).

1.13 The rising amount of air pollution coming from road vehicles has led to a consensus that some measures are necessary to improve air quality. Some of the most important of those introduced by governments have been regulations on the emissions performance of new vehicles

Table 2—Numbers of road vehicles and their contribution to emissions of urban NOx and PM10 in the United Kingdom

Type of vehicle	1990			1995		
	Number of vehicles (thousands)	Total emissions of urban NOx (kilo tonnes per annum)	Total emissions of urban PM10 (kilo tonnes per annum)	Number of vehicles (thousands)	Total emissions of urban NOx (kilo tonnes per annum)	Total emissions of urban PM10 (kilo tonnes per annum)
Petrol car	19,590	335.4	6.7	19,503	266.7	4.8
Diesel car	638	3.5	1.1	1,891	8.4	2.5
Petrol LGVs	1,219	20.9	0.6	779	3.7	0.1
Diesel LGVs	715	9.8	2.2	1,109	21.9	4.4
HGVs	432	83.3	12.7	406	61.6	10.2
Buses	73	40.9	4.1	74	46.2	4.5
Motorcycles	833	1.3	0.6	594	0.8	0.4
Total diesel*	-	137.5	20.2	-	138.1	21.5
Total petrol*	-	357.6	7.9	-	271.2	5.3
TOTAL*	-	495.0	28.1	-	409.3	26.7

* Certain classes of vehicle were not included in the calculation: "total" figures would not be representative of the entire vehicle fleet.

Sources: Department of Transport, *Vehicle Licensing Statistics, 1995* (July 1996), Department of the Environment.

and on the quality of fuels. These measures are outlined more fully in Chapter 3. As a result of anti-pollution strategies, it is expected that pollution from road vehicles will fall over the next decade. However, the Government have stated that there may be a gradual upturn in NOx and particulate matter emissions beyond 2005 as the continuing increase in road traffic begins to outstrip the pace of improvement⁹. The Royal Commission on Environmental Pollution agreed with this assessment, but pointed out that in 2025 emissions from road vehicles of carbon monoxide, volatile organic compounds, NOx and particulate matter would probably still be substantially below their 1990 levels due to measures such as the introduction of catalytic converters to petrol engine vehicles¹⁰.

1.14 The Society of Motor Manufacturers and Traders (SMMT), which represents the United Kingdom's automotive manufacturers, stated that they were "confident" that emissions reductions would not be offset by increasing traffic after 2010 (Q 360). They added that the latest models of transport growth were lower than those which had been used to predict future emissions levels, and that the forecasts do not take into account the improvements expected to result from regulations which will come into effect in 2000 and 2005. This led them to conclude that "the new lower limits for 2000 and 2005 will significantly push out the time after which any increases in overall air pollution from vehicles could happen" (p 147). Nevertheless, the total volume of air pollution attributable to road vehicles will be a major problem as long as the internal combustion engine is widely used.

1.15 In the developed world the amount of air pollutants emitted per new vehicle per kilometre has been falling and is expected to fall consistently for the foreseeable future, as Table 3 indicates. The debate centres on the question of whether this per vehicle improvement will be large enough to offset the predicted increase in road traffic, especially in the developing world where old vehicles are kept running longer and the newest technology may not be applied. The amount of CO₂ emitted per new vehicle per kilometre (in other words, the average fuel consumption of the fleet) has not been falling significantly in recent years¹¹ and, given the continuing growth in the vehicle fleet, CO₂ emissions from road transport may well prove to be a more intractable problem than air pollution.

Table 3—Emissions of air pollutants from a new passenger car

<i>Improvement trend:</i>				<i>Comparative figures for CO₂</i>
<i>(Emission output as a percentage of 1976 baseline)</i>	<i>HC+NOx</i>	<i>CO</i>	<i>PM</i>	
1976 baseline	100	100	100	100
1993 EC Level	10	10	52	120
1996 EC Level	5	5	23	
2000 EC Level (Forecast)	2-3	2-3	<23	

Sources: Ford Motor Company Ltd (p 70); Parliamentary Office of Science and Technology, *Transport: Some Issues in Sustainability* (November 1995).

⁹ *Transport—The Way Forward* (Cm 3234), pp 20-22.

¹⁰ 18th Report, *ibid*, p 127.

¹¹ See *Transport Statistics Great Britain 1995*, p 45. Between 1984 and 1994 the average fuel consumption of new two-wheel drive petrol engine vehicles increased slightly.

CHAPTER 2 REVIEW OF EVIDENCE: VEHICLE TECHNOLOGY

THE INTERNAL COMBUSTION ENGINE

2.1 At an open forum held by the Society of Chemical Industry¹² on the topic of this enquiry the consensus of opinion was that the internal combustion engine should not be written off. Major strides had already been taken to reduce air pollution and there was still great potential for further improvements. The Department of Trade and Industry (DTI) said that "in the five to ten year span, the most important technologies will really be those that deliver incremental improvements in the emissions performance of the internal combustion engine, including both noxious emissions and fuel economy improvements in both petrol and diesel areas". The DTI also thought there would be niche market opportunities for alternative fuels. The main improvements to existing technologies would be in engines and exhaust systems, engine control and management and reductions in vehicle weight (Q 432).

2.2 The twin goals of reducing the emissions of regulated pollutants and improving fuel efficiency (thus reducing CO₂ emissions) are increasingly in conflict (QQ 354, 373, p 72). Since 1993 new petrol cars in the European Union have been equipped with three-way catalytic converters which reduce carbon monoxide, hydrocarbon and NOx emissions by over 90 per cent, but their introduction has forestalled the use of more efficient "lean-burn" combustion (see 2.4). An alternative route to improved fuel economy is to reduce average vehicle size (and weight) and to limit the "parasitic losses" around the vehicle. For example, power steering can cost half a mile per gallon and air conditioning up to two miles per gallon in terms of performance (Q 258). Removing such conveniences from vehicles might be effective, but witnesses cautioned that forcing developments in this way could lead to products that customers did not wish to buy (Q 367, p 75)¹³. Witnesses stated that in the future reductions in emissions of regulated pollutants could only be achieved with exponentially rising costs (Q 371, pp 334, 409), illustrated by Ford Motor Company Ltd with the graph in Figure 1.

PETROL-ENGINE VEHICLES

2.3 Most witnesses agreed that average fuel consumption figures for petrol cars had not improved significantly over the last decade and that there was scope for improvements to be made (eg. QQ 232, 354, p 409). For example, Volkswagen has stated¹⁴ that one of its major long-term goals is to produce an economically viable, versatile, four seater car capable of 130 km/h (80 mph) that would have a fuel consumption of no more than 3 litres/100 km (approximately 100 miles per gallon)¹⁵. Partly because of the age of the overall vehicle fleet, the current average fuel efficiency for all cars on the road in the European Union is thought to be around 9.6 litres/100 km¹⁶. In an attempt to show what can be done with existing technology, a Swiss company working with Greenpeace has recently produced a prototype vehicle based on a Renault Twingo design¹⁷. The car, known as the Smile, has a 360 cc petrol engine with an innovative pressure wave supercharger. Power output is said to be comparable to a 1.4 litre engine, while maintaining a fuel efficiency of 3 litres/100 km. Much of the improvement over the current average fuel efficiency is a function of the small size of the car and associated weight savings.

¹² The Society of Chemical Industry Open Forum was held in London on 25 April 1996.

¹³ The Sierra E-Max, Volkswagen Formel E, and Vauxhall E Drive all suffered poor sales and have been withdrawn from the market (p 75).

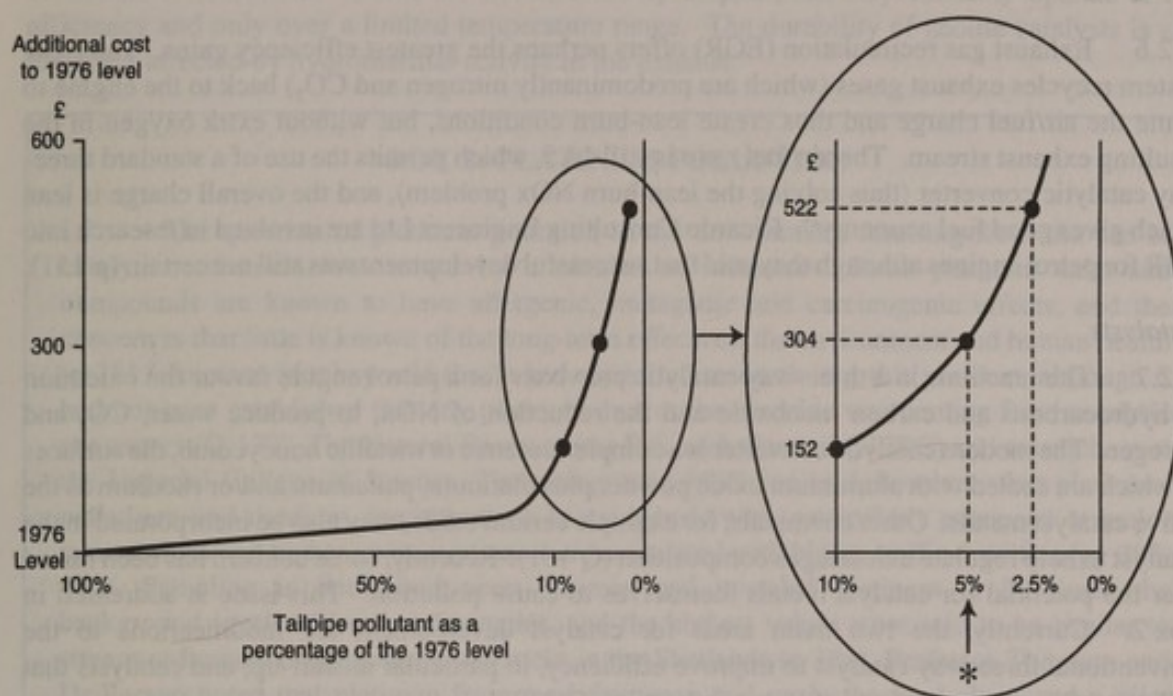
¹⁴ *Volkswagen Environmental Report*, 1996.

¹⁵ Litres and kilometres are used as the standard units throughout the rest of this report. 1 gallon = 4.546 litres; 1 mile = 1.609 kilometres.

¹⁶ European Community Document 4188/96, *A Community Strategy to reduce CO₂ Emissions from Passenger Cars and Improve Fuel Economy* (COM(95)689).

¹⁷ *The European*, 6-12 June 1996.

Figure 1: Product cost versus tailpipe emissions



* Emissions from new vehicles of hydrocarbons, NO_x and carbon monoxide are now at approximately five per cent of 1976 levels (see Table 3). Further measures are expected to incur disproportionately high costs relative to the degree of improvement possible.

Engine technology

2.4 The next major development in petrol engine technology is likely to be the direct injection engine operating at a high air/fuel ratio¹⁸ to maximise combustion, improve fuel efficiency and thus reduce CO₂ emissions (QQ 167, 232, 373, pp 72, 396). With this "lean-burn" technology less fuel is used in each cylinder charge so that the air/fuel ratio is 20–24¹⁹. Lean-running engines were described by Ford as the "ultimate combustion systems for internal combustion" with a 7 per cent improvement in fuel efficiency being possible (Q 259). Figures of 15 to 20 per cent improvement have been quoted²⁰, but as the system goes leaner the temperatures get higher and more NO_x is produced. The amount of NO_x is still lower than from a conventional engine but existing three-way catalytic converters, which are designed for an air/fuel ratio of 14.5, are unable to operate in the oxygen-rich exhaust stream. Thus NO_x emissions from the vehicle are high. Because of the need to comply with emissions regulations, this NO_x problem is the main limitation on lean-burn operation. Ford said that the lean-burn "De-NO_x" catalyst was not yet production ready and the best conversion efficiency achieved so far was only 30 per cent (Q 259).

2.5 A wide range of other possible technological improvements to the petrol engine have also been identified. These include improved electronic engine management, multi valves per cylinder, variable valve control, sequential fuel injection, unthrottled running, optimisation of combustion chamber geometry and exhaust gas recirculation (QQ 232, 300, pp 5, 239, 339). Each of these

¹⁸ This is the mass flow rate of air divided by mass flow rate of fuel.

¹⁹ In current vehicles equipped with three way catalytic converters an air/fuel ratio of about 14.5 is maintained to ensure maximum conversion efficiency of carbon monoxide, hydrocarbons and NO_x. This ratio represents a theoretical balance for complete combustion with no fuel or oxygen left over and is known as the stoichiometric ratio.

²⁰ B Ferris and P Wiederkehr, "Technical options for reducing motor vehicle emissions" in *Chemistry and Industry*, No. 15, August 1995.

would give incremental benefits and the European Commission estimated an overall improvement in engine efficiency of up to 30 per cent (p 239).

2.6 Exhaust gas recirculation (EGR) offers perhaps the greatest efficiency gains. The EGR system recycles exhaust gases (which are predominantly nitrogen and CO₂) back to the engine to dilute the air/fuel charge and thus create lean-burn conditions, but without extra oxygen in the resulting exhaust stream. The air/fuel ratio is still 14.5, which permits the use of a standard three-way catalytic converter (thus solving the lean-burn NO_x problem), and the overall charge is lean which gives good fuel economy²¹. Ricardo Consulting Engineers Ltd are involved in research into EGR for petrol engines although they said that successful development was still not certain (p 151).

Catalysts

2.7 The reactions in a three-way catalytic converter for a petrol engine favour the oxidation of hydrocarbons and carbon monoxide and the reduction of NO_x, to produce water, CO₂ and nitrogen. The modern catalytic converter is a complex ceramic or metallic honeycomb, the surfaces of which are coated with aluminium oxide powder plus platinum, palladium and/or rhodium as the active catalyst metals. Other chemicals, for example cerium oxide, may also be incorporated in the catalyst to help regulate exhaust gas composition (Q 161). Recently, some concern has been raised over the potential for catalyst metals themselves to cause pollution. This issue is addressed in Box 2. Currently, the two main areas for catalyst development are modifications to the conventional three-way catalyst to improve efficiency, in particular at start-up, and catalysts that will operate under conditions of lean combustion (Q 432).

2.8 Using engine management systems to control the exhaust mixture to as close to stoichiometric as possible (Q 162), catalysts already operate at near their ultimate limit and it is unlikely that higher than 97 per cent efficiency could be maintained throughout the useful life of the car²². At present, though, catalysts are highly inefficient just after start-up as it can take a number of minutes for the temperature to reach "light-off" point (the temperature at which the catalyst operates efficiently, usually over 350°C). The time to light-off can be reduced by placing the whole catalyst or a small starter catalyst close to the exhaust manifold. However, conventional three-way catalysts have a stability ceiling of 980°C and thus more thermally durable materials are required (Q 163, pp 74, 271). An alternative is to raise the temperature of the catalyst to its optimum by electrical heating or to combust gases in a chamber within the catalyst (pp 47, 271).

2.9 The main problem at low temperatures is catalysis of the hydrocarbons. One new approach is to collect the hydrocarbons from start-up in a ceramic or zeolite trap, which then releases them back into the exhaust stream after the catalyst has reached light-off temperature (pp 47, 271). Saab have developed a bag to store exhaust gases until the light-off temperature is reached²³.

2.10 For lean-burn systems a combined trap and catalyst arrangement is also under investigation (p 47, Appendix 5²⁴). For example, it may be possible to use a rhodium catalyst dosed with chemicals such as barium to trap the NO_x in nitrate form during lean engine operation. To regenerate the trap the engine is made to run richer (with a lower air/fuel ratio) for a few milliseconds during which the NO_x is reduced in the usual way. The critical barrier to the use of this technology is sulphur in the petrol which, as sulphate, progressively poisons the activity of the NO_x trap chemicals. The lower the level of sulphur in the fuel the better the performance (p 272). A reduction in sulphur content to around 50 parts per million (ppm) was called for by Johnson

²¹ B P M Randall, *Achieving Ultra Low Emission Passenger Cars* (Ricardo Consulting Engineers, 1993). (Paper presented at the British Association for the Advancement of Science.)

²² Information given during visit to Ford Research and Development Centre at Dunton on Tuesday 7 May.

²³ *The Financial Times*, 29 May 1996.

²⁴ Some of the following information was provided by Dr Gandhi of Ford Motor Company and Dr Twigg and Mr Jaffray of Johnson Matthey, at an informal meeting at the House of Lords on 18 July.

Matthey and Ford (Appendix 5, Q 164). Other lean-burn catalysts under investigation are based on zeolite formulations. These are not affected by sulphur, but they currently operate at low efficiency and only over a limited temperature range. The durability of zeolite catalysts is also seriously affected by hydrothermal activity in the exhaust.

BOX 2: PLATINUM POLLUTION

The question of platinum pollution in the environment resulting from the use of catalytic converters was raised by a number of witnesses. Some platinum salts and compounds are known to have allergenic, mutagenic and carcinogenic effects, and the concern is that little is known of the long-term effects on the environment and human health (p 381). Johnson Matthey said that it had supported research into this problem, although it had not been established that any platinum dust at the roadside was coming from catalytic converters (Q 177). The Natural Environment Research Council (NERC) and researchers at the Imperial College of Science, Technology and Medicine said, however, that platinum, palladium and rhodium concentrations in road dusts were particularly enhanced at major intersections and higher concentrations were associated with higher traffic densities (pp 383, 406). Sampling in Richmond upon Thames had revealed platinum at 30 times the background levels of local soil samples, and the highest values were said to be similar to stream sediments from platiniferous rocks in the Shetlands (p 384). Professor Thornton and Dr Farago noted that platinum from road dust may end up in the food chain and a pilot study had revealed "measurable quantities of platinum in blood and urine samples of members of the general population" (p 406). Follow-up research was being proposed by the Imperial College Centre for Environmental Technology (in collaboration with the British Geological Survey and the Institute of Terrestrial Ecology) to establish the human exposure, possible health risks and environmental fate of platinum emissions from catalytic converters (p 383). Additional information on allergies to complex salts of platinum and platinum in the environment was provided by Johnson Matthey (pp 359-365).

Fuel composition

2.11 Changing the composition of a fuel can be the quickest way to reduce vehicle emissions as it affects the whole of the existing fleet rather than just new vehicles as they are introduced. Various petrol reformulations claim to give better performance, improved cold start or lower emissions, and rely either on the use of additives (including detergents) or altering the overall fuel composition. Petrol is a highly complex mixture of hydrocarbons—mostly alkanes with five to ten carbon atoms—and the most efficient fuels with the smoothest combustion characteristics are branched-chain alkanes. Combustion processes are also more efficient if fuels comply with narrow compositional specifications; for petrol maintaining a high octane rating²⁵ is very important. Ricardo stated that "if some non-noxious means of boosting the octane rating of petrol could be obtained then that would be an additional improvement to fuel economy" (Q 390). Organo-metallic compounds containing lead were traditionally used as anti-knock agents. Other metallic fuel additive compounds are discussed in 2.22.

2.12 The addition of oxygenating compounds to petrol is practised widely, and their use is mandated in some states of the USA. The oxygenates (including alcohols) are used to boost octane ratings, improve combustion and thus reduce carbon monoxide and hydrocarbon emissions. One witness said that in the USA the use of oxygenates has resulted in a 15 per cent drop in smog-producing emissions (p 268). In Europe a small volume of processed alcohol, as methyl tertiary

²⁵ The octane rating relates to the antiknock (smooth combustion) properties of the fuel which is determined from the octane number of the base fuel and any additives used. Trimethylpentane, a branched-chain isomer of octane with excellent combustion properties, has an assigned octane number of 100; heptane, a straight-chained alkane with seven carbon atoms, has less controlled combustion properties and an octane number of zero.

butyl ether (MTBE), is used in some petrol formulations as an oxygenate. A report by BMW suggested that a petrol reformulation with low sulphur and benzene content and with 15 per cent MTBE added could potentially reduce carbon monoxide emissions by 30 per cent, hydrocarbon emissions by 20 per cent and NO_x emissions by 15 per cent, but at a cost²⁶. The full benefits of using MTBE and other oxygenates are still under debate and one drawback is increased emissions of aldehydes (p 339). Aldehydes, such as formaldehyde, have a distinctive aroma and are potentially toxic, depending on their ambient concentration.

2.13 Removing certain hydrocarbons from petrol could reduce emissions. For example, reducing the aromatic hydrocarbon content would reduce benzene emissions (from unburnt fuel and benzene formed during combustion), and reducing the olefin content would reduce emissions of NO_x and 1,3-butadiene, which is an olefin combustion product²⁷. Both 1,3-butadiene and benzene are carcinogens for which the World Health Organisation has said there is no safe recommended level in the atmosphere.

2.14 The question of sulphur in petrol has already been raised in relation to De-NO_x catalytic converters for lean-burn systems. Sulphur can also damage exhaust gas sensors and may be a barrier to optimum catalyst performance (pp 13, 74). Johnson Matthey said that the degradation effect of sulphur poisoning on existing catalysts was not a major problem under current regulations, but it would be critical for the higher emission standards expected in the future (Q 175). Johnson Matthey and the German Environment Ministry agreed that timing the introduction of low sulphur fuel will be critical because it will need to be widely available before lean-burn systems with De-NO_x catalysts can be put on the market (Appendices 5 and 6).

DIESEL-ENGINE VEHICLES

2.15 Diesel engines have high durability and low operating costs, making them the main power source for trucks and buses, and one witness contended that for the foreseeable future there was no viable alternative to the diesel engine for the freight user (p 313). Only in the last few decades has diesel power made significant in-roads into the light commercial vehicle and passenger car markets. This has been as a result of improved standards of engineering for small engines, an attractive price differential between petrol and diesel, and superior fuel economy. The Institution of Chemical Engineers stated that energy conversion efficiency for a diesel is over 40 per cent, compared to just 25 per cent for a petrol engine (p 339), and thus diesel-engine vehicles can be 20–40 per cent more fuel efficient on an oil equivalent weight basis (p 240).

2.16 Because of their high fuel efficiency, diesel offers an improvement over petrol in terms of CO₂ emissions. Hydrocarbon and carbon monoxide emissions are also significantly lower than for petrol, but particulate emissions by mass from a diesel engine are more than 25 times greater. The effect of proposed European legislation will be to focus diesel engine developments on further reductions in hydrocarbon and NO_x emissions and also reductions in particulate emissions.

Engine technology

2.17 Much of the development work on heavy duty diesel engines has focused on improving reliability and fuel economy. Most of the engines used are direct injection and the application of turbocharging and intercooling (which increase the mass of air entering the engine) has brought about major improvements in combustion efficiency (pp 151, 424). There is, however, a trade-off between reducing NO_x by lowering the charge temperature with intercooling, and using higher temperatures for more complete combustion and lower particulate emissions (p 423). Further adaptations to improve combustion include high pressure fuel injection and the use of four valves per cylinder (pp 73, 151, 396). The direct injection four valve per cylinder diesel engine was described by Ford as being "close to the theoretical limit of efficiency" for an internal combustion

²⁶ BMW, *Fuels for Road Vehicles of the Future—An analysis of the technical and economic factors and options* (1995). Referred to subsequently as the "BMW report".

²⁷ House of Commons Environment Committee, 1st Report (1994–95): *ibid* (HC 39).

engine, but like the lean-burn petrol engine its use could be prevented by over-strict NOx emission regulations (p 74).

2.18 For small diesel engined vehicles, including passenger cars, indirect injection has been favoured because of its smooth quieter operation, high power output and wider range of operating speeds compared to heavy duty direct injection systems. Improvements have now been made in direct injection performance and refinement and Ricardo said that there was a general trend towards using high speed direct injection diesels in almost all the next generation of diesel passenger cars. Direct injection was said to be 10–20 per cent more fuel efficient than indirect injection (Q 388, pp 151, 377). Continued improvement of direct and indirect injection diesels for passenger cars is likely to include: revisions to combustion chamber geometry and electronic fuel injection to improve combustion; refinements to reduce lubricating oil consumption; and electronically controlled exhaust gas recirculation to lower combustion temperatures and reduce NOx emissions. In addition, direct injection diesels are also likely to use high pressure fuel injection, intercooling, and multivalves per cylinder (pp 6, 72–4, 151, 240)²⁸. The European Commission predicted that these incremental changes would give a 30 per cent improvement in fuel consumption on the urban cycle compared to 1991 technology (p 240).

Fuel composition

2.19 Diesel, like petrol, is a complex mixture of hydrocarbon compounds—mostly with 13 to 25 carbon atoms. The diesel equivalent to the octane rating is the cetane index: the higher the cetane index the greater the ease with which the fuel ignites under compression, and the smoother the engine operation. A high cetane index is also important for good fuel economy (Q 391). A number of other fuel parameters can be varied to achieve a range of effects in emissions performance, including: lowering the density, which reduces particulate emissions; reducing the polyaromatic hydrocarbon (PAH) content to produce more benign hydrocarbon emissions; altering the distillation temperature of the fuel which reduces particulates but increases hydrocarbon emissions; removing sulphur; and using fuel additives, two of which are discussed below (eg. Q 655, pp 30, 423–4). Witnesses reported often contradictory results with different diesel formulations tested under different conditions and, in particular, effects varied according to vehicle size (p 30, Appendix 6)²⁹.

2.20 Most witnesses agreed, however, that sulphur content was a major factor and they supported the lowering of sulphur in diesel as a means of reducing particulate emissions (QQ 164, 391, 402, 432, pp 137, 383, 423, Appendices 5 and 6). Low sulphur diesel produces fewer particulates in the exhaust stream of even unmodified vehicles, and it would also allow various exhaust clean-up technologies (including catalysts and particulate traps) to be used. By October 1996 all diesel sold in the European Union must conform to sulphur concentrations of 500 ppm or less (Q 679). Although this is a significant reduction from the previous limit of 2000 ppm, Ricardo and Johnson Matthey said that this was not low enough because De-NOx catalysts and traps were very sensitive to sulphur content (Q 391, Appendix 5). Johnson Matthey suggested that 50 ppm sulphur would be a suitable standard. In some Scandinavian countries, however, air quality regulations require the use of very low sulphur diesel containing less than 10 ppm sulphur. A diesel fuel meeting these standards, "Greenergy City Diesel", is only available in small quantities in the United Kingdom from a few petrol stations in London. A trial of City Diesel by Westminster City Council showed an average reduction of 37 per cent in exhaust smokiness (p 421). Some of the larger bus companies in London are now negotiating with petroleum companies for the supply of City Diesel³⁰. An alternative very low sulphur fuel for use in diesel engines is biodiesel, produced from vegetable oils, which is described in 2.31–2.34.

²⁸ See also Ricardo Consulting Engineers, *Automotive Diesel Engines and the Future*.

²⁹ See also BMW report, *ibid.*

³⁰ *Green Futures*, no. 1, October 1996, pp 7–8.

2.21 Three witnesses (the Automobile Association (AA), Mobil Oil Company Ltd and Clean Diesel Technologies Inc. (CDTI)) were rather less supportive of moves towards low sulphur diesel. Mobil said it expected that more sulphur-tolerant catalysts could be developed (Q 670) and both Mobil and CDTI favoured the use of fuel additives instead. Concerns were raised over the extra costs to the refining industry, the limited production capacity in the United Kingdom and the fact that the fuel would also have a negative effect on CO₂ production (QQ 392, 605, 608, 664, 676–681). Switching to low sulphur diesel fuel would also require the use of lighter distillate fractions, which could have serious implications for aviation fuel (which is currently produced from these lighter fractions) (Q 664). In the light of all of these factors, the AA said that it was opposed to very low sulphur diesel being made compulsory (Q 605).

2.22 The CDTI fuel additive system used a soluble platinum compound as an in-engine catalyst, which was said to improve fuel economy slightly and make some reductions in the emissions of particulates, carbon monoxide and hydrocarbons (p 289). The fuel additive favoured by Mobil is an organo-metallic compound containing manganese. Diesel with this additive was said to give an emissions performance equivalent to the very low sulphur Scandinavian diesel (eg. 23 per cent reduction in hydrocarbon and 30 per cent reduction in particulate emissions), but at much lower cost (QQ 655, 659, 664, 665). Similar manganese fuel additives have already been used in North America, although they have been the subject of concern on health grounds³¹, and Ricardo said that their attitude to such compounds was now one of "extreme caution" (Q 402). CDTI and Mobil said, however, that they had carried out full health and safety analyses of their products.

Catalysts and particulate traps

2.23 Low volume platinum oxidation catalysts, which favour reactions that convert hydrocarbons and carbon monoxide to water and CO₂, are already in use on many diesel passenger cars and light goods vehicles. These catalysts may actually increase NO_x emissions because of the oxidising conditions in the exhaust stream, but can assist in reducing particulate emissions (pp 47, 272, 374).

2.24 Particle traps and filters are under development to reduce particulate emissions further. The Automobile Emissions Control by Catalyst group (AECC) described a ceramic wall filter which could remove up to 90 per cent of particulates in diesel exhaust (p 272). The main problem with traps is that they clog quickly and thus need to be cleaned or "regenerated" frequently, which involves burning the trapped carbon particles to produce CO₂. The low temperature of diesel exhausts is not favourable for regeneration, but catalytic coatings on the filter can lower the temperatures at which the particles burn. Similar results can be achieved using catalytic additives, including copper, platinum, manganese and cerium oxide, either added to the fuel or to the exhaust gases just ahead of the trap (pp 9–10, 272, 285). The Johnson Matthey continuously regenerating trap (CRT) takes a different approach. The CRT is used in conjunction with an oxidation catalyst to boost the NO_x concentration in the exhaust, and this extra NO_x then acts as an oxidant to burn off the trapped particles at less than 300°C (Appendix 5, pp 9, 272). The use of both oxidation catalysts and particle traps is optimised with low sulphur fuel (pp 9–10, 47, 424). On-going problems with particle trap technology include cost (typically £2,800 to £6,300 per system) and long-term durability (pp 8–11, 293, 374–5, Lucas p 11).

2.25 To meet European Union Stage III limits for emissions it is likely that NO_x will have to be removed from diesel exhausts, and similar problems apply to this as for petrol lean-burn combustion. De-NO_x catalysts already under development use reagents added to the exhaust gases ahead of the catalyst to help in the catalytic reduction of NO_x to nitrogen. One system uses urea added from a canister and another uses extra fuel or another hydrocarbon reagent, for example liquefied petroleum gas (pp 46, 284–5). The German company MAN said that initial tests of the

³¹ G Wood & M Egyed, *Risk assessment for the combustion products of Methylcyclopentadienyl manganese tribarbonyl (MMT) in gasoline* (Environmental Health Directorate, Canada, 1994).

urea system for larger vehicles showed a 61 per cent reduction in NO_x (Appendix 6). The system using fuel as a reagent had achieved NO_x reductions of up to 40 per cent, but only under ideal conditions (p 47).

2.26 The development of efficient particulate traps and De-NO_x catalysts was described by Ricardo as the most significant technical hurdle to be overcome for diesel engines (p 151). The European Commission suggested that it might be more fruitful to limit hydrocarbon emissions from all sources (to suppress the formation of ozone through reactions between hydrocarbons and NO_x) to avoid having to set stringent NO_x targets for diesels which might never be met (p 240).

Durability

2.27 One of the main problems with diesel engine vehicles is their durability and thus the very slow replacement rate of the vehicle fleet. Volvo estimated that the bus replacement cycle was around 20 years (p 424) and the SMMT said that nearly 60 per cent of trucks and buses (most of which have diesel engines) in the United Kingdom were 10 or more years old (p 149). Rapid improvements to emissions from this portion of the diesel fleet are thus only possible through fuel modifications or through the retrofitting of new technology to the vehicles (see 3.10).

ALTERNATIVE FUELS FOR THE INTERNAL COMBUSTION ENGINE

Introduction

2.28 A recent study by the Energy Technology Support Unit (ETSU) provides an in-depth analysis of alternative fuels for road transport³². The report considered the whole life-cycle of fuels from initial production/extraction phases through processing and distribution to end use in the vehicle. Some of the main findings are quoted in the sections below. Another useful review was published by BMW in 1995³³.

2.29 Most of the alternative fuels and associated technologies discussed here are still under development, although liquefied petroleum gas, natural gas and ethanol have a long history of use as road transport fuels. Much of that experience, however, has been outside the United Kingdom. Where the use of an alternative fuel is not already widespread a number of common problems arise: the lack of a refuelling infrastructure, and high costs because the scale of operation, fuel and vehicle production are not economically viable. In many instances vehicles are not optimised to run on the alternative fuel, because of its lack of availability, and can for example use petrol as well. Although this is useful for establishing a market, the full emissions benefits from use of the alternative fuel may not be realised.

2.30 An additional problem is that, apart from prototypes, all vehicles have to be type approved for emissions according to the fuel used (Q 6). There are no European-wide standards for fuels other than petrol and diesel and thus approvals have to be sought in each Member State. In the United Kingdom the Department of Transport provides exemptions for each individual vehicle using an alternative fuel, and regulations are currently being amended to allow the type approval of vehicles operating on compressed natural gas and liquefied petroleum gas (QQ 6-7).

Biodiesel

2.31 Biodiesel is a renewable energy source that can be produced from a variety of vegetable oils including rapeseed, sunflower, soya and palm oils. The oils are reacted at moderate temperature with methanol in the presence of a sodium or potassium hydroxide catalyst, to produce biodiesel and glycerine as a byproduct³⁴. Biodiesel produced from rapeseed oil is known as rape

³² Energy Technology Support Unit (ETSU), *Alternative Road Transport Fuels- A Preliminary Life-cycle Study for the UK* in two volumes (March 1996). This research was co-funded by the Department of Transport and the Department of Trade and Industry. This report is subsequently referred to as the "ETSU report on alternative fuels". A summary of its findings is presented in Appendix 7.

³³ BMW report, *ibid.*

³⁴ DTI/ETSU, *A Review of the Potential of Biodiesel as a Transport Fuel* (1992).

methyl ester (RME). The British Association of Bio Fuels and Oils (BABFO) said that the cost of producing biodiesel was 2.5 times higher than for mineral diesel (Q 624). Some of this extra cost was usually offset by selling the useful byproducts: glycerine, for industrial and food uses; straw (for fuel); and crushed rapeseed, which can be used as a high protein cattle feed.

2.32 The potential CO₂ savings associated with RME are significant: one study suggested that they could be as high as 1.5 kg CO₂ per litre when RME is used to replace mineral diesel³⁵, though RME is not CO₂-neutral because of the energy used in the agricultural and processing stages. BABFO said the ratio of energy created to that required to produce a saleable product was about 3:1 for biodiesel, compared to 7:1 for mineral diesel (Q 617). The energy ratio could be slightly improved by recycling used frying oils as a biodiesel feedstock, which is already done in Italy and Austria where used oils are collected from hotels and restaurants to be turned into RME (QQ 614–615, 641), and it might also be possible to increase yields by research into the genetic engineering of crops. Also included in the life-cycle analysis for RME is the production of nitrogen fertiliser from natural gas feedstocks, a process which releases large amounts of CO₂. Some other problems associated with biodiesel are the loss of biodiversity as mono-culture crops are grown, the volumes of pesticide used and the potential for nitrates (from the fertiliser) to leach into runoff and ground water³⁶. Biodiesel itself is fully biodegradable. The ETSU report on alternative fuels suggested that just seven per cent of 1992 United Kingdom diesel demand could be met if all set-aside land in the country at that time was put under oilseed rape for use as an RME feedstock.

2.33 Biodiesel can be used in almost any diesel engine with little or no modification being required³⁷ (Q 613, pp 224, 311). The physical and chemical properties, and health and safety factors, are very similar to mineral diesel although it is slightly more corrosive to certain engine and fuel line components. Biodiesel can also be used as an oxygenating additive in mineral diesel (Q 621). Exhaust emissions of carbon monoxide, hydrocarbons, and particulates from biodiesel, and the carcinogenicity of the particulates, are all lower than from mineral diesel (Q 612, pp 14, 224, 281), although different reports suggested a variety of levels of improvement depending on the application, engine type and test cycle used. Biodiesel is also an extremely low sulphur fuel and produces almost no sulphur dioxide on combustion. Negative aspects include higher NO_x and aldehyde emissions and the odour of exhaust fumes.

2.34 The ETSU reports on biodiesel and alternative transport fuels said that, on the basis of technology, biodiesel was the simplest direct substitute for conventional road fuel. Production capacity in the United Kingdom was the main drawback and it was likely that supply would only meet the demand for certain niche markets unless there was a major change in land use policy. The National Farmers' Union supported the use of biodiesel and other liquid biofuels in areas of environmental sensitivity (p 379). The Royal Mail said that it was already involved in trials with RME and that it was to extend its trials to consider blends of RME and mineral diesel (p 401).

Alcohols

2.35 The alcohols ethanol and methanol are used widely as alternative road fuels in a number of countries, although at present there is no distribution infrastructure for alcohol fuels in the United Kingdom. The alcohols may be used pure (pure ethanol is denoted as E100, pure methanol as M100), blended with petrol (eg. M85, with 15 per cent petrol) or used in small quantities as a petrol additive. The alcohols can be produced from hydrocarbon feedstocks (principally natural gas for methanol) through catalytic cracking and hydration reactions or through the fermentation of organic materials (typically sugar beet or maize, but also rice straw, wood pulp and other agricultural waste (p 224)). Alcohols are biodegradable and the bio-alcohols are a renewable

³⁵ As above.

³⁶ Netherlands Environmental Forum, *Environmental and Energy Aspects of Liquid Biofuels* (1993).

³⁷ For example, all Volkswagen diesel vehicles sold after August 1995 can run on biodiesel without modification (*Volkswagen Environmental Report*, 1996).

energy resource. However, the area of agricultural land needed to meet a significant proportion of transport fuel requirements with alcohols could be impractical.

2.36 The ETSU report on alternative fuels suggested that the CO₂ benefits from bio-alcohols are significant and similar to biodiesel. Emissions of carbon monoxide, hydrocarbons and NO_x from alcohol combustion rank between those from petrol and diesel³⁸, and particulate emissions from the vehicle are almost zero. Particulates are, however, released in the fuel production phase (ie. through farming). The high octane rating of alcohols permits the use of higher compression ratios and thus increased fuel efficiency: the BMW report suggested an 11 per cent efficiency improvement over petrol for an engine operating on M85, and said that further improvements in fuel consumption and power output could be achieved with optimised engines. Specialised engines are already used in Brazil where E100-E95, produced from sugar cane, is an important road fuel (Q 613).

2.37 There are a number of disadvantages associated with the use of alcohol as a fuel: the low energy density requires the use of larger fuel tanks if vehicle range is to be maintained; alcohols are highly corrosive to certain engine and fuel system components, and thus modifications are needed if high concentrations are used; pure alcohols also have poor cold start characteristics, although this can be improved with blends including 15 per cent petrol (pp 14–15, 330³⁹). Both ethanol and methanol are more expensive than petrol and diesel (p 330). There are also health and safety risks associated with alcohols. E100 and M100 flames are virtually invisible in daylight, pure alcohol vapour in an enclosed space can ignite, and methanol was described as being highly toxic (pp 14, 330, 347).

2.38 In the USA the formulation E10, sold as gasohol, accounted for one per cent of total petrol sales in 1995 (p 224). E10 is used in unmodified spark ignition engines⁴⁰ as an oxygenate, and to increase the octane rating of the fuel. Ford said that it was involved in calibrating and developing engines for gasohol and alcohol fuels in South America and that the company was maintaining a watching brief on all technologies (Q 232). In Europe alcohols are often processed to Ethyl or Methyl Tertiary Butyl Ether (ETBE and MTBE) which are used as petrol additives to reduce carbon monoxide and PAH emissions (pp 14–15, 30, 311). The ETSU report on alternative fuels concluded that bio-alcohols could be advantageous both in reducing urban pollution and in reducing CO₂ emissions.

Liquefied petroleum gas

2.39 Liquefied Petroleum Gas (LPG) is a mixture of propane, butane and iso-butane. LPG may be produced in small quantities directly from natural gas liquids or in larger volumes from crude oil during refining, although this is often less energy efficient than burning the original feedstock (Q 694, p 344). LPG can be stored in vehicles in lightweight pressure vessels at around 14 bar (compared to around 200 bar for compressed natural gas).

2.40 Use of LPG as a transport fuel in the United Kingdom has declined over the last decade and now there are fewer than 1500 LPG vehicles in operation⁴¹. In Italy there are more than one million vehicles, in the Netherlands half a million, and in Japan 300,000, including most of the taxi fleet. The Liquid Petroleum Gas Association (LPGA) suggested that the high level of fuel duty on automotive LPG in the United Kingdom, even after the 15 per cent cut in duty announced in the 1995 Budget, was a major factor in LPG's decline (p 369).

2.41 The LPGA claimed that LPG has a number of environmental benefits over other road fuels, including: lower carbon monoxide emissions compared to petrol in city driving (although still

³⁸ With a lean burn catalyst the NO_x emissions could be improved further.

³⁹ See also BMW report, *ibid*, pp 14–15.

⁴⁰ Parliamentary Office of Science and Technology briefing note 41, *Biofuels for Transport* (1993).

⁴¹ *ENDS Report*, no. 246, July 1995.

higher than for compressed natural gas and diesel); NO_x emissions significantly lower than from diesel (and similar to petrol); total hydrocarbon emissions similar to diesel in city driving, and petrol on average; very low particulate emissions (less than from petrol); and very low emissions of toxic hydrocarbons. Similar findings were reported by ETSU. Disadvantages included a 5–10 per cent reduction in power output, and a greater volume of fuel required for a similar range, compared to petrol, if vehicles were not fully optimised⁴² (p 12). The Confederation of Passenger Transport said that the catalytic converter required to achieve the full potential for reduced emissions needed to be replaced every 2–3 years (p 292). There were also some questions over the safety of LPG which, because it is denser than air, had the potential to collect in low-lying pockets if spilt and could pose a fire risk. Underground parking of LPG vehicles was thus usually not allowed in most countries where they were operated (p 346). There may also be safety implications for LPG vehicles using long tunnels such as the Channel Tunnel.

2.42 The ETSU report on alternative fuels concluded that LPG was the only alternative fuel to offer operating costs equivalent to petrol and diesel, and that considerable savings in NO_x and particulates could make LPG suitable for use in urban fleet vehicles as a replacement for diesel. Whole life-cycle CO₂ emissions from LPG use ranked between those of petrol and diesel.

Natural gas

2.43 Natural gas offers the attraction of both environmental benefits and of providing a huge additional source of hydrocarbon energy (Q 382, pp 113, 121). Natural gas is predominantly methane (CH₄), although compositions vary according to the source⁴³. For use in road vehicles the fuel can be stored either at high pressure as compressed natural gas (CNG) or cooled below -161°C as liquefied natural gas (LNG). British Gas said that a third storage option, where the gas is adsorbed onto activated carbon at ambient temperature and one fifth the pressure of CNG, was likely to be on the market in 5–6 years time (Q 326). The adsorbed system would be more appropriate for the passenger car market because gas compression costs would be lower and the storage vessel need not be cylindrical.

2.44 The equivalent octane rating of natural gas is very high (around 140), permitting the use of high compression ratios and lean combustion. The ETSU report on alternative fuels said that CNG combustion produces lower CO₂, NO_x and sulphur dioxide emissions than LPG, petrol or diesel, carbon monoxide emissions intermediate between LPG and diesel, and almost zero particulates. The Natural Gas Vehicle Association (NGVA) stated that, compared with petrol, carbon monoxide emissions were reduced by 76 per cent, NO_x by 83 per cent and non-methane hydrocarbons by 88 per cent, on an urban operating cycle (p 127). Life-cycle hydrocarbon emissions are higher than for petrol or diesel, although over 85 per cent of the total is methane. Emissions of more complex hydrocarbons including benzene and PAHs are considerably lower than from petrol combustion, thus reducing the potential for ozone (and summer smog) formation. The ETSU report concluded that CNG was one of the most appropriate fuels for reducing urban air pollution and that, with LPG, it was also the most likely alternative fuel to be favoured on economic grounds.

2.45 British Gas and the NGVA said that natural gas vehicle (NGV) technology is proven and on the road in over 1 million vehicles and in more than 40 countries. There are, however, only around 350 NGVs in the United Kingdom and the main barrier to expansion was thought to be the high rate of fuel duty. Safety, limited refuelling infrastructure and gas availability were not considered to be problems (pp 102–104, 123). The success of NGVs in Italy (300,000 vehicles, 280 refuelling stations) and Argentina (400,000 vehicles, 500 refuelling stations) in particular was said to be due largely to significant economic support from their governments (Q 314, p 105). The Japanese government is spending ¥1.3 billion (c. £7.5 million) in 1996 on a promotional subsidy

⁴² The majority of LPG vehicles in operation are bi-fuel vehicles also capable of running on petrol. Fully optimised LPG vehicles can run at a higher compression ratio and thus achieve greater fuel economy.

⁴³ D C Carslaw & N Fricker, "Natural Gas Vehicles" in *Chemistry and Industry*, No.15, 1995.

for natural gas vehicles and nearly ¥1 billion (c. £5.7 million) to fund the installation of refuelling stations for electric vehicles and NGVs (Ministry of International Trade and Industry, Japan, unprinted evidence); the goal is to have over 200,000 NGVs on the road in Japan by the year 2000. In the United Kingdom, British Gas and the NGVA called for natural gas excise duty to be reduced to the EU minimum of 7.8 pence/kg as an incentive for operators to switch to natural gas (pp 105, 123) (see 3.27)⁴⁴. With a critical mass of users established, economies of scale could be realised which would reduce the cost of NGVs; the Confederation of Passenger Transport said that, currently, the cost of a CNG bus was 30 per cent more than the diesel equivalent (p 292). The lack of a home market was also thought to be hindering research and development in the United Kingdom and was the greatest barrier to exploiting the major export potential for the supply of dedicated natural gas vehicles and systems (QQ 347, 349, p 126).

2.46 The majority of NGVs are spark-ignition petrol engine vehicles that have been converted to operate on both petrol and CNG (bi-fuel operation) to overcome the problems of a restricted refuelling infrastructure. The most recent generation of NGVs are mono-fuel with fuel injection and catalysts that are semi-optimised for methane (Appendix 5). Exhaust emissions could be improved still further with increased emphasis on dedicated natural gas engines, and the development of palladium-based methane oxidising catalysts to deal with unburnt methane in the exhaust stream (QQ 336–7, pp 152, 396). Although methane does not have a major effect on air quality, its global warming potential is approximately 24 times that of CO₂ (p 12). A study by a Dutch research agency concluded that CNG ranked between petrol and diesel when considering the combined global warming impacts of CO₂, NO_x and methane⁴⁵. British Gas, however, claimed that CNG had a lower global warming impact than both petrol and diesel (p 107).

2.47 Compressed natural gas is currently stored on NGVs at 200 bar in a high pressure vessel. Witnesses including the Department of Transport and DTI identified these cylinders as a potential safety risk (pp 13, 172). However, British Gas, the NGVA and the Institution of Chemical Engineers assured the Committee that rigorous international safety standards already existed, and that there was great experience of handling and storage of CNG and with the refuelling systems used (pp 107, 125, 346). The Institution of Chemical Engineers added, however, that extending sales of CNG to the private motorist might present a hazard (p 344). Positive safety factors with natural gas are that it would disperse in the atmosphere in the event of a leak, the high ignition temperature (c. 700°C) reduces the risk of fire starting, and in the event of fire the storage vessels would vent in a controlled manner rather than explode.

2.48 Several witnesses suggested that CNG was at present more suited to high mileage depot-based commercial fleets operating in urban areas because of the high vehicle costs and limited refuelling infrastructure (Q 304, pp 105, 152, 344, 425, Appendix 6). The Royal Mail indicated that a major disadvantage to operators was the need to change from diesel technology to spark ignition engines⁴⁶, which would have capital investment implications for both vehicles and workshops (p 401).

2.49 The cost of a refuelling station for a bus operator with up to 25 buses was estimated by British Gas to be between £250,000 and £400,000, depending on the type of system used (Q 312). The gas compressor was the most expensive component and thus slow-fill refuelling with a smaller compressor and reduced need for on-site gas storage was a cheaper option. A slow-fill home refuelling system costing around £4000 and running off the home gas supply would refill a passenger car in 6–7 hours (Q 322). For a full sized refuelling station with the capacity of a standard petrol filling station the cost was estimated to be around £750,000 (Appendix 5).

⁴⁴ The House of Commons Environment Committee also recommended a reduction in duty to the EU minimum in its 1st Report (1994–95), *ibid* (HC 39).

⁴⁵ *ENDS Report*, no. 246, July 1995.

⁴⁶ Diesel engines can be converted to natural gas, but a new cylinder head block is required.

2.50 British Gas said that most of the major European motor manufacturers were involved in NGV research, and that there were co-ordinating bodies at national, European and international levels (pp 107–108). The NGVA said research in the past had been fragmented and was now suffering from commercial short-termism (p 125). The main areas identified for further research included the development of lightweight and low cost gas storage tanks, methane catalysts, and engine management systems that could adapt to wide variations in fuel quality and composition (eg. pp 120–121, 152, 172, 396)⁴⁷.

2.51 Liquefied natural gas (LNG) requires refrigeration and insulated storage and presents certain different technical problems from CNG. BMW has research expertise in this area and has been operating an LNG test vehicle since 1995. Use of LNG could increase the operating range of natural gas vehicles and it could be an intermediate stage of development between CNG and vehicles using liquified hydrogen as a fuel (p 106).

Hythane

2.52 Hythane is a mixture of 95 per cent natural gas (methane) and 5 per cent hydrogen. Research in the USA has shown that hythane offers some improved combustion characteristics over natural gas, resulting in a significant reduction in NO_x emissions (Q 340, p 124). Mr David Hart of The Imperial College of Science, Technology and Medicine believed the benefits of hythane could be considerable and that “the introduction of hythane into city centres merits serious attention”⁴⁸. It would be uneconomical to add hydrogen to distributed gas supplies, but it could be added at the fuelling station or from a separate cylinder carried on the vehicle (p 121). British Gas said “the route to the hydrogen vehicle is through compressed natural gas and the combination of hydrogen and natural gas is one of the stages towards that” (Q 340).

Hydrogen

2.53 The Volkswagen Environmental Report stated that hydrogen⁴⁹ as a fuel for combustion engines was a proven technology which eliminated emissions of CO₂ and virtually all of the pollutants associated with the burning of hydrocarbons. The technology was, however, described as complex and high cost, and no short-term markets were foreseen⁵⁰. The main problems were poor performance (power output being roughly half that of a petrol engine), question marks over safety and the lack of a supply infrastructure. Carrying enough hydrogen on a small vehicle was another major problem. Storage in metal hydride form or onboard fuel processing from methanol were potential solutions being examined by Johnson Matthey (QQ 136, 139–140, and Appendix 5). BMW has tested four generations of hydrogen powered vehicles and has concluded that the best on-board storage system for hydrogen is in liquified form at -253°C. The company is hoping to use technical solutions from its work with CNG and LNG vehicles and adapt them to the challenges of liquid hydrogen: difficulties with refuelling, maintaining gas-tight fuel systems and the safety properties of storage tanks were major concerns. The BMW report stated that it would probably be necessary to use robots for refuelling.

Other fuels

2.54 *Di-methyl ether* (DME) is an alternative fuel for use in compression ignition engines. The fuel can be manufactured from natural gas or directly from methanol. DME is a gas and requires storage under moderate pressure to liquefy it for use. Fuel costs are expected to be at least 20 per cent higher than for diesel and engine modifications are required because the fuel is

⁴⁷ See also BMW report. Further information was supplied by the Ministry of International Trade and Industry, Japan.

⁴⁸ David Hart and Professor Nigel Lucas, “Hydrogen as a Transport Fuel and Externality Costing”.

⁴⁹ The generation of hydrogen is discussed in 2.62.

⁵⁰ Volkswagen Environmental Report 1996, p 56.

corrosive (p 344). Exhaust emissions are claimed to contain no sulphur, almost no particulates, reduced hydrocarbons and 20 per cent of the NO_x compared to diesel combustion⁵¹.

2.55 A-21 is a joint fuel project between Caterpillar and A-55 Limited Partnership under development in the USA. The fuel is an emulsion of naphtha (65 per cent), water (30 per cent) and a surfactant (5 per cent) designed for use in heavy duty diesel engines with only minor modification. A-21 has a low combustion temperature which is claimed to reduce emissions of NO_x and particulates by 39 and 42 per cent respectively, without loss in engine performance (Caterpillar, unprinted evidence).

FUEL CELLS

2.56 The fuel cell has a long history, having been invented in the nineteenth century, but its practical application appears to have been largely restricted to specialist, military and aerospace uses, including NASA's moon-buggies where expense was not of primary concern. While various prototype vehicles have been built over the last 30 years or so, intensive research into the use of fuel cells in road vehicles is a relatively recent development, stimulated by pressures for reductions in emissions, and in particular the desire for zero emission transport.

2.57 The fuel cell operates on the principle of the reverse process of electrolysis; it transforms energy stored in gaseous or liquid fuel into electricity by electro-chemical oxidation, producing water and some heat at the same time. It is in many ways comparable to a battery, but with the important advantage of having an external fuel supply so that capacity is only limited by the amount of fuel that can be stored on board, with refuelling when required. The fuel is usually hydrogen or methanol, which may be used directly or transformed into hydrogen by an on board reformer. A diagram of the working of a proton exchange membrane fuel cell, which several witnesses argued was the most developed in terms of commercial road vehicle production, is shown in Figure 2.

2.58 There are five basic types of fuel cell which are characterised by the electrolyte that they employ. Three of these operate at low or intermediate temperatures: alkaline fuel cells (70–200°C), phosphoric acid fuel cells (PAFC) (150–210°C) and solid polymer fuel cells (SPFC), also known as proton exchange membrane fuel cells (PEMFC) (80–110°C). The others require high temperatures for operation: molten carbonate fuel cells (550–650°C) and solid oxide fuel cells (SOFC) (1000–1100°C). The alkaline fuel cell represents the oldest fuel cell technology and is used on the space shuttle. Its use in vehicles is currently restricted by a requirement for oxygen free of CO₂. The PAFC was developed in the 1970s to heat and power large spaces, and while power density is too low for use in cars, it might be suitable for heavy duty vehicles⁵². Johnson Matthey considered that it was at the pre-commercial demonstration stage for road transport but primarily applicable to stationary uses (p 47). Evidence on the application of fuel cells in road vehicles was primarily concerned with SOFCs and SPFCs.

Solid polymer fuel cells

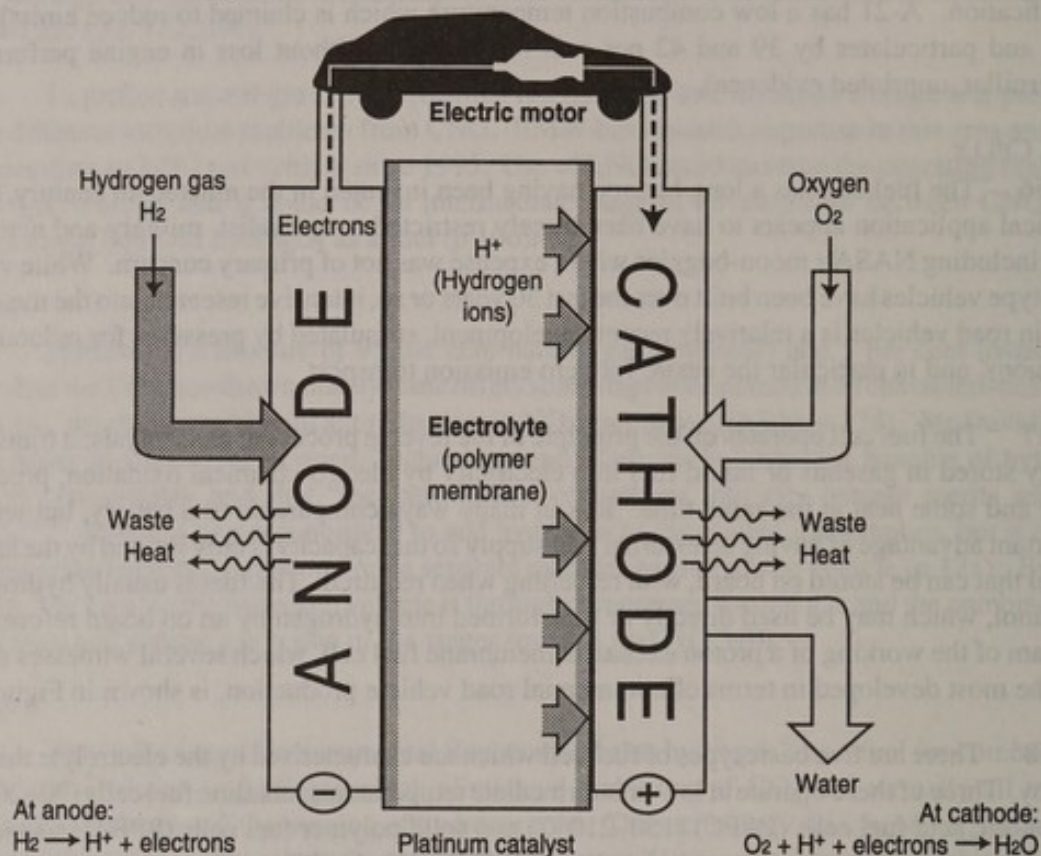
2.59 The SPFC normally uses hydrogen as the fuel, with the electrolyte being a thin polymer membrane. It requires a platinum or platinum-ruthenium catalyst which at present appears to necessitate the use of direct hydrogen fuelling as poisoning by carbon monoxide will take place if this is produced by reformation of methanol on board. Research into the reduction of carbon monoxide emissions during reformation is in progress (pp 317, 403). Evidence was received from a number of individuals and organisations that the SPFC was at the most advanced stage for vehicle applications (eg. Q 114, p 47). Johnson Matthey is collaborating with Ballard Power Systems of Vancouver on the production of SPFC-powered urban buses (Q 136). The buses are equipped with fibre glass reinforced aluminium pressure cylinders in the roof for hydrogen storage and are currently at the stage of a small demonstration fleet with a range of 250 miles and 60 passenger capacity. Full commercialisation is planned in 1998, with 75 passenger capacity buses and a 350

⁵¹ *The Economist*, 11 March 1995.

⁵² Graham Harrop, *The Future of the Electric Vehicle* (Financial Times Management Report, 1995), p 46.

mile range. Ballard is also working in partnership with Mercedes-Benz, Honda and others in the production of fuel cell powered cars. Mercedes-Benz has produced a prototype New Electric Car (Necar II), using Ballard SPFCs, with a range of 250 km, top speed of 110 km/h and 6 passenger capacity (Appendix 6).

Figure 2—Proton Exchange Membrane Fuel Cell



(reproduced from R H Williams, "The Clean Machine", in *Technology Review*, p 23, with the kind permission of Perugi Design.)

2.60 A major issue for the SPFC is the storage of hydrogen on board, this being particularly intractable for smaller vehicles, with urban buses clearly being seen as the practicable option in the near future. Research was being carried out into adsorption onto a metal hydride, but there were major practical problems. The alternative solution to the problem of storage is the use of a liquid fuel such as methanol. However, the problems in reforming this to hydrogen have led to research being carried out into fuel cells in which methanol can be used directly as the fuel, but this is not yet at an advanced stage (p 318). We received much more information on the direct use of methanol by advocates of the SOFC. The US Department of Energy is supporting a project to produce methanol powered buses for Georgetown University; this involves both a PAFC bus and a PEMFC bus (p 48). Some automotive manufacturers have suggested that it may be possible to develop SPFCs which could run on gasoline-type fuels for which a production and distribution network already exists⁵³. Mr Williams viewed direct methanol cells as the most attractive option, on the grounds of reliability and storage of fuel (Q 541, p 203). Active research was underway in the United Kingdom, but cost of the catalyst was a major problem. He indicated that £3 million over three years would be needed to produce a prototype bus using this system.

⁵³ Energy Technology Support Unit (for DTI) and EPSRC, Fuel Cells UK Newsletter, Issue 3 (September 1996).

Solid oxide fuel cells

2.61 In an SOFC, a solid oxide ceramic material conducting oxygen ions is used as the electrolyte. The cathode is exposed to air where ionisation takes place with diffusion through the electrolyte to the anode where the fuel, usually methanol, is oxidised resulting in an electric current being created. Evidence was presented that the SOFC was still at the research stage (p 47), and that the high operating temperatures caused a long warm up delay⁵⁴. A lower operating temperature would improve efficiency and reduce warm-up delay and Professor Steele stated that he was currently developing a small scale unit operating at 500°C, which it was predicted would be available for a demonstration vehicle in two to three years' time (p 403). An important feature of this type of cell is that the carbon monoxide acts as part of the fuel rather than as a catalyst poison. The strongest advocate of the SOFC was Dr Copcutt, who was critical of the use of hydrogen as a fuel because of its explosive properties. He emphasised the recent improvements in SOFCs, resulting in reduced costs of the ceramics, and his own research which allows start up to operating temperature within seconds, using a small diameter tubular cell technology. Dr Copcutt had built a small car using this advanced SOFC technology and argued that SOFC powered cars would replace the internal combustion engine within 10–50 years (pp 293–295). The use of liquid methanol in the SOFC is a massive advantage as it does not need to be stored in a bulky high pressure cylinder; the current refuelling infrastructure is geared towards the transportation of liquids. Witnesses were concerned that commercially practicable SOFC vehicles, while highly desirable, were far less advanced than SPFC vehicles. At present SPFCs only appear suitable for bus operation, and SOFCs would seem to offer better prospects for small vehicles.

Fuel

2.62 The prime environmental advantage of the fuel cell is that it does not produce toxic gases during use and, in the case of hydrogen cells, only emits water. Thus its advantages in terms of urban air quality are unquestionable. However, both hydrogen and methanol use energy in their production and there is the possibility that the widespread introduction of fuel cell vehicles might merely transfer emissions to the site of fuel production. Currently hydrogen is largely produced by steam reformation of natural gas or coal gasification, while methanol can be produced from natural gas or naphtha. Both methanol and hydrogen can, however, be produced from renewable sources, using biomass production and solar energy; in addition hydrogen can be produced using nuclear power. There are major technical and cost problems in the use of renewables for this purpose (p 336). Mr Hormandinger stated that of the options for hydrogen production, biomass and solar energy are the most expensive and reformation of gas or coal are the cheapest (p 320). Hydrogen power was described as the ultimate goal by the Japanese Ministry of International Trade and Industry, although this was likely to take 30 years to be realised⁵⁵.

Costs

2.63 Besides evidence on the costs of hydrogen production, a considerable amount of evidence was received on the current, projected and targeted costs of production and operation of fuel cell vehicles. Johnson Matthey indicated their cost target for a bus fuel cell power plant was \$150 (c. £100) per kW, which was within easy attainment, but that cars, which have a much lower capital cost, would require \$40–50 (c. £25–35) per kW which would involve considerably more development work. The US Programme for a New Generation of Vehicles was aiming at \$30 (c. £20) per kW with a \$1500 (c. £1000) fuel cell system in a \$20,000 (c. £15,000) car. Mr Williams felt that £10 per kW would be a reasonable objective for a car and noted that at present the direct methanol cell, which he advocated, required £400 per kW for the catalyst alone. Mr Hormandinger stated that in Germany the aim was \$140–280 (c. £95–185) per kW for the production of 100,000 vehicles by 2005. Mr Hormandinger compared the life cycle costs of a fuel cell bus with those of a diesel bus, with the latter showing a 23 per cent advantage over the former.

⁵⁴ Harrop, *ibid.*, p 46.

⁵⁵ Information supplied by the Ministry of International Trade and Industry, Japan.

Timescale

2.64 Opinions on the timescale in which fuel cells would become viable ranged over a considerable period, with the most pessimistic evidence being from the Natural Gas Vehicles Association, who viewed the fuel cell as a "holy grail" (p 125). The consensus of opinion was that widescale use in passenger vehicles would probably take place within 10–20 years. However, there were hints that major technological breakthroughs might move this timescale forward, with firmer detail on this being kept secret.

BATTERIES

2.65 Electric vehicles powered by batteries have been around as long as internal combustion powered vehicles. However, at an early point in the history of mechanically powered road transport, it became clear that the internal combustion engine was a clear winner over all other forms. Consequently, from the 1930s onwards, on-road electric vehicles were largely confined to specialist short haul, low speed uses. There are around 20,000 battery-powered electric road vehicles in the United Kingdom, the great majority of which are milk floats and other specialist vehicles. Batteries are made up of a number of linked electrical cells. Each cell consists of two electrodes immersed in a conducting electrolyte, and converts internally stored chemical energy into direct current. In a battery powered vehicle the electricity generated is used to drive an electric motor which powers the wheels.

2.66 An electric motor is more efficient than an internal combustion engine, but when used in a battery electric vehicle its efficiency is offset by a number of other factors, including weight, power losses in electricity generation and distribution, and recharging. From the evidence we received it was clear that the greatest limitation to the large-scale introduction of electric vehicles at the present time was the battery, although the infrastructure for recharging also played an important role. Ford stated that "today, battery technology does not permit production of EVs that meet customer expectations of range, price and convenience" (p 75). One advantage batteries possessed over the internal combustion engine was that batteries can store the energy which is usually lost as heat when the brakes are applied to the wheels. This system of recharging the battery while braking is known as regenerative braking, which the European Commission estimated could lead to a 10–12 per cent reduction in total energy consumption (p 241).

The lead-acid battery

2.67 The lead-acid battery is the most common type used in electric vehicles and represents a long-established, reliable and tested technology. However, lead is very heavy, with the result that such batteries have low specific energies of about 108 kilo Joules per kilogram (kJ/kg)⁵⁶, which means that the energy equivalent of one litre of petrol has to be stored in 320 kg of battery⁵⁷. The battery has a life of only three years. The latest lead-acid battery car produced by General Motors weighs 1350 kg, of which 533 kg is battery. It has a range of 115–135 km, costs \$30,000 (c. £20,000) and requires a 15 hour recharge with a 110 volt or 3 hours with a 220 volt electricity supply⁵⁸. Ricardo stated that for a pure electric car to be viable a specific power of 300–400 W/kg was required, compared with the 70–140 W/kg achieved with lead-acid batteries (p 145) (see Table 4). The European Advanced Lead-Acid Battery Consortium was formed in 1994 with a four year programme to improve this type of battery, aiming at 180 kJ/kg specific energy, 150 W/kg specific power, 100 per cent recharge in four hours and a cost of less than \$42/MJ (c. £28/MJ). We received details from Powergen and Wavedriver on the Wavedriver system which employs electronics to improve performance of electric vehicles with converted batteries, including fast charging on-board and prolonging the battery life. It will be introduced into a Denis Dart Electric Bus to be launched in Southend in late 1996 (pp 390, 429–30).

⁵⁶ Most of the evidence received quoted figures in watt hours per kilogram (Wh/kg). The conversion factor is 1Wh=3600J. 1KWh=3.6 mega Joule (MJ).

⁵⁷ *Automotive Environment Analyst*, no. 18, July 1996.

⁵⁸ General Motors Press Release, 4 January 1996.

Other batteries

2.68 Another battery is the nickel-cadmium (NiCd) type, which has a long history of use in devices such as cameras. It is being used in a number of electric cars, produced by Peugeot-Citroen and Renault, including those that are being employed in a large scale trial in the French city of La Rochelle. The NiCd battery has 198 kJ/kg specific energy, 100–200 W/kg specific power, and a life cycle of 2000 recharges (compared with about 600 for a lead-acid battery), but is expensive, costing about £54/MJ. A Citroen car currently being developed which has a NiCd battery is aimed at achieving a range of 210 km outside and 110 km inside urban areas, with a maximum speed of 110 km/h. The German Ministry of Education, Research and Technology indicated that this type of battery had the greatest potential for cost reduction if mass produced. The Ministry was carrying out a large scale test programme on the island of Rügen, comparing the performances of vehicles with NiCd batteries, and two advanced high temperature batteries—sodium-nickel chloride and sodium-sulphur (Appendix 6). A related battery is the nickel-metal hydride type, which is being developed in conjunction with General Motors. This has considerable potential, and has achieved a specific energy of 342 kJ/kg, but currently costs £360/MJ and is unlikely to reach a commercially viable price until some time into the 21st Century.

2.69 We received evidence on a number of more advanced batteries, some of which operate at high temperature. The Ford Motor Company has developed a sodium-sulphur battery which operates at 300°C for use in its Ecostar van which was demonstrated to the Committee⁵⁹. It has a range of up to 160 km with specific energy and power of 288–504 kJ/kg and 90–130 W/kg, respectively. Evidence received on the Committee's visit to Germany indicated that problems had been experienced with sodium-sulphur batteries in the Rügen trial, due to the high battery temperature causing a fire. However, the Electric Vehicles Association considered that this safety problem had been exaggerated and that tests in Germany had shown that the batteries could survive severe impact undamaged (p 60). Another high temperature battery is the sodium-nickel chloride or ZEBRA, which has high energy and power densities and a long life cycle, with twice the energy storage capacity of a lead-acid battery. It is currently expensive, however, and evidence from the European Commission indicated that while it was probably ready for commercial development, with costs projected to fall, it was not efficient for low mileage operations as self-discharge was required to heat the batteries (p 241). A considerable amount of experience in the use of this battery has been obtained following a three year trial by Mercedes-Benz.

2.70 Evidence was received from several sources on the likely future importance of lithium batteries, both lithium-ion and lithium-polymer. Several witnesses argued that the lithium-ion battery, which stores twice as much energy as conventional batteries, was the most attractive longer term option (pp 77, 173, 241). It was apparent that this was a technology being pursued by the Japanese, where 120 million ecus (c. £96 million) was being invested in their development. Towards the end of the enquiry we received preliminary details of the lithium-ion battery developed by Sony, who claimed high performance with energy and power densities of 360 kJ/kg and 300 W/kg, with a range for a car of 200 km; however, no costs were quoted and all the evidence received indicated that this is currently an expensive option. The European Commission's Task Force on the Car of Tomorrow (see 3.36) aims to reduce the current cost of a small electric car to near the cost of an equivalent internal combustion engine vehicle.

Infrastructure

2.71 Much evidence was received on the infrastructural problems which needed to be overcome before the large-scale introduction of electric vehicles would be possible. Recharging batteries was a time-consuming exercise, with the most practical option being overnight charging. The Electric Vehicle Association (EVA) stated that it was in discussion with London Electricity to provide private access charging points outside houses (Q 204). The La Rochelle experiment had installed public recharging sites, but these were little used. The EVA suggested that "opportunity

⁵⁹ The Ecostar van was demonstrated to members of the Committee on Thursday 18 April 1996.

The following table, adapted from information supplied by Ricardo Consulting Engineers Ltd, sets out the status and requirements for some of the various battery technologies (pp 154-55).

Table 4—Status and Requirements for Batteries

<i>Cost—£MJ</i>	<i>Required</i>	<i>Present</i>
Lead-Acid	20-30	15-30
Nickel-Iron		30-55
Nickel-Cadmium		40-55
Nickel-Metal Hydride		30-40
Sodium-Sulphur		30-55
Sodium-Nickel Chloride		55-85
Lithium Polymer		5-70
<i>Specific Power—W/kg</i>	<i>Required</i>	<i>Present</i>
Lead-Acid	300-400	70-140
Nickel-Iron		70-140
Nickel-Cadmium		100-200
Nickel-Metal Hydride		150-200
Sodium-Sulphur		100-150
Sodium-Nickel Chloride		100-150
Lithium Polymer		75-100
<i>Specific Energy—kJ/kg</i>	<i>Required</i>	<i>Present</i>
Lead-Acid	360-720	70-215
Nickel-Iron		145-250
Nickel-Cadmium		125-250
Nickel-Metal Hydride		180-290
Sodium-Sulphur		270-540
Sodium-Nickel Chloride		270-360
Lithium Polymer		450-360
<i>Energy Density—kJ/l</i>	<i>Required</i>	<i>Present</i>
Lead-Acid	540-1080	180-290
Nickel-Iron		215-430
Nickel-Cadmium		215-430
Nickel-Metal Hydride		540-720
Sodium-Sulphur		270-450
Sodium-Nickel Chloride		450-630
Lithium Polymer		360-430

<i>Life-Years</i>	<i>Required</i>	<i>Present</i>
Lead-Acid	5-10	2-3
Nickel-Iron		3-5
Nickel-Cadmium		?
Nickel-Metal Hydride		5-10
Sodium-Sulphur		?
Sodium-Nickel Chloride		3-5
Lithium Polymer		?
<i>No. of Discharge Cycles</i>	<i>Required</i>	<i>Present</i>
Lead-Acid	500-1000	500-1000
Nickel-Iron		500-2000
Nickel-Cadmium		1500-2000
Nickel-Metal Hydride		750-1000
Sodium-Sulphur		250-750
Sodium-Nickel Chloride		500-750
Lithium Polymer		250-500

recharging" could be provided by provision of points at places such as supermarkets and restaurants (Q 201). It appeared that the provision of public recharging points was to some extent a psychological necessity, as it gave the driver confidence in being able to operate the vehicle freely. The infrastructural problems were viewed by Ford as a major barrier to the development of the market (p 76). The short life and high cost of batteries was seen as another major problem and a number of sources suggested that some form of hire or lease of batteries would be appropriate. It was also suggested that exhausted batteries could be removed from the vehicle and exchanged for fully charged ones, removing the need to wait while the battery was recharged (pp 273, 297).

Environmental impacts

2.72 A number of studies have been carried out on the environmental impacts of battery-powered compared with internal combustion engine vehicles, taking into account the generation of electricity required to power battery vehicles. A Parliamentary Office of Science and Technology (POST) report quoted studies which showed benefits from electric vehicles in terms of reduced CO₂, NO_x and carbon monoxide emissions, but increased sulphur dioxide emissions, with the current United Kingdom generating mix⁶⁰.

2.73 The Royal Commission on Environmental Pollution considered that emissions from energy production were largely offset by environmental problems associated with the possible release into the environment of toxic materials such as cadmium and lead in the batteries⁶¹. It was apparent that full life cycle costs, which include factors other than energy production, have yet to be calculated and thus it is difficult to judge which type of power-source is more environmentally friendly. The EVA and the European Advanced Lead Acid Battery Consortium emphasised, however, that recycling of lead-acid batteries is a well proven, economic procedure which is widely practiced.

⁶⁰ Parliamentary Office of Science and Technology, *Transport: Some Issues in Sustainability* (November 1995), p 33.

⁶¹ 18th Report, *ibid*, p 143.

ALTERNATIVE TECHNOLOGIES

Gas turbines

2.74 Mobile gas turbines are used in aircraft, some ships and even in tanks. Air is compressed in a rotating compressor, heated in a combustion chamber and then expanded through a turbine which both drives the air compressor and provides energy for propulsion. The gas turbine has very low emissions of air pollutants due to its continuous combustion process—the European Commission stated that it would have no difficulty in meeting the Californian Ultra Low Emission Vehicle (ULEV) limits for air pollutants (p 240)—and it can operate on a variety of fuels.

2.75 There are, however, several practical difficulties which restrict its potential for widespread use in road vehicles. Perhaps the most important is the unsuitability of the turbine for variable load applications (for example the acceleration and deceleration of a vehicle). Similarly, the turbine is most efficient at high loads whereas vehicle propulsion units frequently operate at very low loads. Partly because of this the small prototypes developed for use in road vehicles have had high fuel consumption. To approach the fuel consumption levels of the internal combustion engine witnesses stated that it will be necessary to raise turbine inlet temperatures, which in turn requires the development of advanced ceramic materials which can cope with very high and very variable temperatures (pp 154, 240). Ricardo estimated that such materials were “at least ten years” away, especially when the need to keep costs down was considered. In their opinion the cost of a gas turbine which could be used in a road vehicle was unlikely to decline beyond the point where it would be anything other than “an article of conspicuous consumption” (Q 408). If there was pessimism that the gas turbine could be used as the prime mover for road vehicles, there was optimism from some witnesses that a small turbine could be used in a hybrid configuration (pp 106, 139, 397) (see 2.79–2.83).

External combustion engines

2.76 Like internal combustion engines, external combustion engines are powered by pistons driven by the expansion and contraction of gases. Unlike the internal combustion engine, the heat needed to expand the gas is not generated within the piston cylinder itself, but is supplied externally through the burning of fuel elsewhere. Certain forms of external combustion engine have been investigated for their potential to power road vehicles. Witnesses considered that while engines such as the Stirling or Rankine cycle engines are highly efficient and have very low exhaust emissions, they are probably unsuitable for powering road vehicles (pp 153, 397). One witness stated:

“Of the external combustion cycles the Stirling cycle provides the most promise with high efficiencies and very low exhaust emissions. The Stirling engine is, however, immensely complex, bulky and expensive to produce and is not considered to be in close competition with internal combustion engines” (p 149).

Flywheels

2.77 Flywheels are energy storage systems and can therefore be described as mechanical batteries. Energy is stored in a wheel spinning in a vacuum at up to 200,000 revolutions per minute (p 241), which can be charged up from an electrical source. The most advanced flywheels have very low levels of energy loss and the total amount of energy stored can be comparable to chemical battery systems. The system is relatively energy efficient in comparison with existing chemical batteries⁶², and the Royal Academy of Engineering reported that flywheels possessed energy storage levels around 60 per cent better than those of a nickel-cadmium battery (p 397). Another strength of the flywheel is that it can be charged and discharged rapidly, meaning that flywheel vehicles would have good specific power and that recharging could be achieved in a similar time to that taken to refuel a conventional petrol or diesel vehicle. Flywheels were also reported to have long operational lives, characterised by one witness as “near infinite” (p 397). The major barriers

⁶² Harrop, *ibid*, p 51.

to the introduction of flywheels identified were those of cost and containment, which are to a degree interlinked (p 397)⁶³. The need to ensure that the flywheel does not escape from its secure containment, especially during a crash, will increase the weight of the system and means that it may be difficult to reduce the price to a level where flywheels can compete directly with the internal combustion engine. The SMMT and Rover Group also contended that to date it had only been possible to develop small size units which required frequent external recharging (pp 138, 393). It is possible that flywheels might be used as the energy storage component of a hybrid system (see 2.79).

Other technologies

2.78 It is not possible to examine all the methods suggested to propel a vehicle in this Report. Some research has been conducted into the potential of ultracapacitors to store a large enough electrical charge to power a vehicle, though in recent years attention seems to have focused on chemical batteries and other energy storage devices such as flywheels. Ford argued that ultracapacitors might be a useful means of adding to the power output of an electric vehicle, or in other words, for use in a hybrid system (p 79). It has also been suggested that a solar panel on the roof of a vehicle might supplement a battery⁶⁴. The limited availability of sunlight in many parts of the world means, however, that it is unlikely that solar power could make a significant contribution to the energy needed to power a vehicle unless there were orders of magnitude reductions in vehicle weight.

HYBRID TECHNOLOGIES

2.79 The first five sections of this chapter have considered the potential of various technologies to be the primary power source for a road vehicle. At present, internal combustion engines are the dominant power source in the overwhelming majority of vehicles. They do contain a battery to start the engine and to power auxiliary functions such as electric windows, but the internal combustion engine is the primary power source. Many witnesses suggested that in the future two or more power sources might be used to drive a vehicle (pp 156, 263, 355, 358, 402). Several combinations of energy generators and energy storage devices have been suggested, for example an internal combustion engine-chemical battery combination; a gas turbine-flywheel (p 426); or a fuel cell-chemical battery (p 203).

2.80 The main advantage of a hybrid system is that the peak demands on the generator can be smoothed out by tapping the energy storage system, which makes it possible for the generator itself to be smaller, giving advantages in both emissions and fuel economy (Professor Acarnley of the University of Newcastle stated that simulation studies indicate possible fuel savings of 30 per cent (p 263)). A second advantage is that if energy is drawn exclusively from the storage unit and the generator is turned off the vehicle will have a limited "no emissions" range; a particular advantage for urban driving. Outside urban areas the storage device could be recharged by the energy generator. A further benefit is that hybrid systems also make regenerative braking possible (see section 2.66). The hybrid could also be a useful means of introducing new technology to the market gradually. Professor Acarnley stated that it is possible to produce hybrid vehicles "which are attractive to the general public in terms of performance and which can be viewed as stepping stones towards zero emission vehicles" (p 263). The future of hybrids may therefore be as a link between existing and new technologies.

2.81 One commonly cited example of a hybrid vehicle is an internal combustion engine-battery combination. When the engine is running at a low load it could be used to charge the battery, and at high load (for example during periods of acceleration) the battery could provide extra energy to drive the wheels. In the case of this specific example, there might be a substantial emissions benefit because the internal combustion engine could be run at a steady state rather than

⁶³ See also Review of the Research Program of the Partnership for a New Generation of Vehicles, 2nd Report (1996), p 12.

⁶⁴ Harrop, *ibid*, p 35.

fluctuating between heavy and low loads, which decreases the efficiency of the engine. In other words, a hybrid vehicle might be able to capitalise on the performance advantages of the internal combustion engine while reducing its adverse effects.

2.82 Volvo has produced a gas turbine/nickel-metal hydride battery truck with a "no emissions" range of around 25 kilometres⁶⁵. Other hybrid prototypes include the VW Golf Electro-Hybrid, which possesses a diesel engine and a chemical battery. The diesel engine is only used when the car moves off and above speeds of 60 km/h. The vehicle is said to produce only 40 per cent of the NO_x and 70 per cent of the CO₂ of an equivalent diesel vehicle⁶⁶. JCB Research suggested a hybrid battery-single cylinder diesel engine, which they claimed could cut fuel consumption by over 50 per cent with a zero emissions range of 50 kilometres at 48 km/h (pp 356–8).

2.83 One drawback of hybrid vehicles is that they make use of two separate systems, and therefore will inevitably be more complex—and more expensive—than single propulsion units (p 241). The added complexity and weight of the twin propulsion systems might mean that hybrids are only viable in large vehicles (Q 212). The main technical problem with hybrids is still the energy storage capacity of the storage device (Q 343). A hybrid vehicle is itself a recognition that there is no single technology ready to replace the internal combustion engine. This led some witnesses to argue that hybrids could only be a commercially viable proposition if legislation were introduced to establish "no emissions areas" in towns and cities (Q 343), or mandatory low fuel consumption levels (pp 156, 398, 426). The widely held view that hybrids could only become established through some form of Government intervention was seen as a drawback by the NGVA, which argued that the hybrid should not be used as a "sop to 'political' pressures" (p 125).

⁶⁵ Volvo brochure *Environmental Concept Truck*, p 12.

⁶⁶ Volkswagen *Environmental Report 1996*, p 52.

CHAPTER 3 REVIEW OF EVIDENCE: POLICY

INTRODUCTION

3.1 As we stated in the first chapter of the Report there are a host of measures which have been introduced, or which are proposed, to improve air quality and to reduce the amount of fuel consumed by road vehicles. In this Chapter we will largely concentrate on those methods which may bring about improvements in the *technology* of those road vehicles and their fuels; in other words measures which will not only have a direct effect on air pollution and CO₂ emissions, but will also stimulate the development of new technology and assist that technology to be successful in the market place.

AIR POLLUTION

3.2 The measures which are examined below are part of overall strategies to reduce air pollution, especially in urban areas where the problem is most severe. In August 1996 the United Kingdom became the first European Union Member State to produce a draft *National Air Quality Strategy*⁶⁷. The British strategy focuses on four main areas: improvements in vehicle and fuel technology; tighter controls on the existing vehicle fleet; environmental responsibilities for fleet operators, especially public fleets; and changes in planning and transport policies. The European Commission intends to produce draft Directives on air quality.

Emissions limits for new cars

3.3 Many countries now demand that all cars sold after a certain date must comply with pollution standards which specify the amount of pollutant a vehicle may emit per kilometre over a standard test driving cycle. For example, in 1993 the European Union introduced maximum limits (the "Stage I" limits) for the amount of carbon monoxide, hydrocarbons and particulates that a passenger car can produce. The practical effect of these emissions limits was that all new petrol engine cars sold in a European Union Member State from 1993 onwards had to be fitted with catalytic converters. The limits will be strengthened for cars produced from 1997 onwards (Stage II), and new measures to come into effect in 2000 and 2005 are currently under negotiation (Stage III and Stage IV). This progressive tightening of emissions limits partly reflects advances in technology and is partly designed to stimulate technological advances.

3.4 In order to calculate the correct level for emissions limits the European Commission undertook a lengthy study involving the automotive and oil industries to identify the most cost-effective means of meeting World Health Organisation air quality guidelines by the year 2010. The results of this "Auto-Oil" study were then used to feed into the political process of determining the new emissions limits for vehicles⁶⁸. There are different limit values for petrol and diesel engine vehicles, and there are separate emissions limits for vans and lorries. The Commission has calculated that the proposed vehicle emissions limits for 2000 will add between 200 and 520 ecus (c. £150–£400) to the cost of a new car⁶⁹. Ford stated that the proposed 2000 limits would add £360 to the cost of a car compared to one which met Stage II limits (p 74). The following table demonstrates the progressive tightening of emissions limits for new cars in the European Union and also sets out the emissions limits dictated by the American state of California. The Californian standards differ from the European Union approach in stipulating that a certain proportion of the vehicles sold in the state in a specified year must conform to the various standards. For example, 25 per cent of new vehicles sold in 1997 must conform to the Low Emission Vehicle (LEV) standard.

⁶⁷ *ibid.*

⁶⁸ The Auto-Oil study also examined fuel quality standards; see 3.7.

⁶⁹ European Community Document 9856/96, *Communication from the Commission to the European Parliament and the Council on a future strategy for the control of atmospheric emissions from road transport taking into account the results from the Auto-Oil Programme* (COM(96) 248 final), p 21.

Table 5—New passenger car emissions standards in the European Union and California

European Union							
Year	Stage	Vehicle type	Emissions limits in grammes/kilometre				
			CO	HC+NOx	HC	NOx	PM
1993	Stage I	Petrol and diesel	3.16	1.13			0.18
1997	Stage II	Petrol	2.20	0.50			
		Diesel, indirect injection	1.00	0.70			0.08
		Diesel, direct injection	1.00	0.90			0.10
2000 ⁽¹⁾	Stage III	Petrol	2.30		0.20	0.15	
		Diesel	0.64	0.56		0.50	0.05
2005 ⁽¹⁾	Stage IV	Petrol	1.00		0.10	0.08	
		Diesel	0.50	0.30		0.25	0.025
California ⁽²⁾							
Standard		CO		HC+NOx			
Transitional Low Emission Vehicle (TLEV)		2.94		0.50			
Low Emission Vehicle (LEV)		2.94		0.33			
Ultra Low Emission Vehicle (ULEV)		1.76		0.28			

⁽¹⁾ The Stage III and IV limits have not been finalised.

⁽²⁾ The Californian standards have been adjusted by the RCEP to indicate what emission levels vehicles complying with those standards would achieve in the different test cycle used in the EU.

Sources: Royal Commission on Environmental Pollution, 18th Report, *ibid*; European Community Document 9856/96, *ibid* (COM(96) 248 final), p 10.

3.5 There was general agreement that the emissions standards for new vehicles introduced in the European Union had been a major success in reducing emissions of pollutants both from individual vehicles and overall from the entire fleet (pp 79, 126, 355, 384, 392, 397, 403, 423). There was some discussion on the extent to which emissions standards could be used to drive technological developments. While the Government conceded that this was a legitimate role for regulations, they warned that the "function needs to be used wisely and carefully" (Q 452). Ford noted that governments needed to collaborate with industry in the development of standards, "to ensure that the regulations which ultimately emerge are feasible and have the commitment of all the involved parties" (p 79). The strength and the weakness of emission standards in driving forward technology is illustrated by the Californian approach. While the regulations have

stimulated a great deal of research and brought about far less polluting vehicles (the Ultra Low Emission Vehicle limits will probably be achieved without great difficulty), the 1998 mandate for the introduction of Zero Emission Vehicles has been postponed as the state accepted that these vehicles are not yet ready to come on to the market.

3.6 One of the criticisms made of the European Union emissions standards was not the value of the limits themselves, but that they are measured by an unrealistic test cycle which does not give an accurate indication of emissions in real driving conditions. The Commission stated that they had combined an "urban" cycle with an "inter-urban" cycle, adding that in the new test cycle the 40-second "warm up period" during which emissions were previously not counted was being removed (Q 722)⁷⁰. However, the test is carried out at 25°C, which is far higher than the average temperature in European countries (Q 404), and one witness stated that the test understated the true extent of low speed driving (when emissions are likely to be higher) in normal conditions on British roads. The Institute of Road Transport Engineers stated that:

"Correlation between these standards, the levels found in service through periodic roadworthiness checks and the actual levels of concentration in the atmosphere at various locations and times is scant" (p 333).

The Commission conceded that any test cycle could always be improved, and that the results of long term tests on vehicles actually in use could eventually result in modifications to the test cycle (Q 724).

Fuel quality standards

3.7 Another way to tackle the problem of air pollution is to alter the fuel which is used in engines. In developed countries fuels for road transport must conform to standards laid down by governments. As with the new vehicle emissions limits, within the European Union those standards are set by the European Commission. The question of fuel quality standards has increasingly become linked to the question of new vehicle emissions limits, to the extent that the Auto-Oil Programme was a joint examination of both emissions limits and fuel standards. It concluded that, within Auto-Oil's terms of reference, anti-pollution measures aimed at vehicles would generally be more cost-effective than measures aimed at fuels. Nevertheless, the Commission has proposed that existing fuel quality standards be tightened in both 2000 and 2005. It has made proposals for the year 2000 standards, and has stipulated that new standards for 2005 should be brought forward in 1998. The Directive to come into effect in 2000 will regulate the volatility and the aromatics, benzene and sulphur content of petrol, and the polyaromatics and sulphur content of diesel. The Commission predicts that the new fuel quality standards for 2000 will make petrol approximately 0.14 pence/litre and diesel approximately 0.59 pence/litre more expensive⁷¹.

3.8 Despite the conclusions of the Auto-Oil programme, some witnesses argued that alterations to the fuel used in road vehicles would have a more immediate effect in the short term than emissions standards for new vehicles because both old and new vehicles would be affected by such a change, while new vehicles would take time to come on to the market and replace older ones. The question of fuel composition has become controversial as some automotive manufacturers have argued that advanced anti-pollution devices such as lean-burn traps will not work unless very high quality fuel is available. This technical question is addressed in Chapter 2.

3.9 Another form of regulation is to mandate the use of additives; the French Government has proposed to make the addition of bioadditives (fuels derived from agricultural crops) to road fuel compulsory by the year 2000, while in some parts of the United States oxygenates are used to

⁷⁰ This is especially important as standard three-way catalytic converters do not begin to work until they have warmed up; see 2.8.

⁷¹ Government Explanatory Memorandum on European Community Document 9856/96, *ibid* (COM(96) 248 final), p 8.

reduce carbon monoxide emissions (p 268) (see 2.12). The European Commission does not consider that it is necessary to require the use of oxygenates (Q 695).

Older vehicles

3.10 Some witnesses considered that too much effort was going into driving down emissions from new cars ever further and that not enough was being done to tackle emissions from older vehicles. The AA stated that around ten per cent of the vehicles on the road cause 50 per cent of the pollution (Q 605). Three main options were identified by witnesses for the control of emissions from the existing vehicle fleet. These were frequent emissions tests which would require regular vehicle maintenance, the fitting of pollution control devices or less polluting parts and scrappage schemes to remove old polluting vehicles from the fleet entirely.

- (a) **In-service maintenance:** Several witnesses affirmed the importance of good maintenance of vehicles in keeping down emissions of pollutants. At present, some countries enforce emissions standards for the existing vehicle fleet. In the United Kingdom, for example, there are emissions standards determined by the age of a vehicle⁷², which are checked both at the annual roadworthiness or MOT test and during spot-checks at the road-side by the Vehicles Inspectorate. These standards are far less severe than those for new vehicles, but they are intended to force vehicle owners to maintain their vehicles properly. The Government have announced that regulations will be drawn up to allow local authorities to stop vehicles and check emissions at the roadside⁷³, as part of their general approach to allow local authorities to respond appropriately to their own situation. However, there has been some concern that the Government is dragging its feet and that funds will not be made available to support this new power⁷⁴. The Transport Research Laboratory argued that "more realistic in-service tests and stringent particulate and/or smoke limits for diesel vehicles could be applied ... Market forces could then dictate whether the costs of achieving these strict limits could justify their use with respect to the costs of operating vehicles on other fuels" (p 410).
- (b) **Retrofitting:** Some witnesses stated that it would be possible to fit pollution control devices to older vehicles, or even to replace parts or entire engines. For petrol engine vehicles it is theoretically possible to strip the engine and to fit new fuel injection and spark systems. In reality, retro-fitting petrol vehicles is probably not worthwhile because the costs would be much greater than the value of the car (QQ 238, 363-4, 429). Similarly, witnesses stated that it was generally impractical to fit new engine technologies to older diesel engine designs of around a decade ago because of oil consumption problems, although piston and cylinder modifications could be made. For more up to date diesel engines, advanced injection equipment, oxidation catalysts and particulate traps could be retrofitted (Q 400, pp 8-11). Although catalysts and particulate traps were expensive, Ricardo said that most retrofits were relatively simple and relatively cheap: the cost for an old truck to have an engine overhaul, new injection equipment and new combustion chambers was estimated to be £1000, on a non-profit basis. This remedial action could reduce NOx and particulate emissions by 70 per cent, and give a fuel economy gain of 5 per cent (QQ 424, 428).
- (c) **Scrappage schemes:** The vehicle manufacturers stated that one of the main problems in improving air quality was that the new low emission vehicles they were producing were not coming on to the market quickly enough. The SMMT claimed that if all vehicles in the United Kingdom more than 10 years old were scrapped and replaced by new vehicles, emissions would fall by 25 per cent immediately and by 50 per cent by the year 2002. They argued, along with Ford, that a series of scrappage schemes in which financial

⁷² See The Road Vehicles (Construction and Use) (Amendment) (No. 5) Regulations 1995, 1995 S.I. 2210.

⁷³ *Transport—The Way Forward* (Cm 3234), p 57.

⁷⁴ *The Times*, 19 August 1996.

incentives were given to scrap old vehicles (ensuring that parts and especially engines were not re-used) could "make a major contribution to improved air quality" by replacing gross polluters with the latest technology (p 141). The Government agreed that "the rate of replacement of the vehicle parc is a major factor in reducing total emissions" (p 171), but stated that discussions with the automotive industry on the subject of scrappage schemes had so far come to nothing (Q 442). The European Commission indicated that the effectiveness of a scrappage scheme would vary from country to country, depending on the number of cars not equipped with catalytic converters (Q 727). ICI noted that EC studies indicate effective inspection and maintenance are more effective than early scrappage subsidies in controlling pollution (p 326).

CARBON DIOXIDE EMISSIONS

Targets

3.11 At the 1992 Rio Summit the United Kingdom, along with 150 other countries, committed the itself to stabilising emissions of CO₂ at 1990 levels by the year 2000. Negotiations will soon be underway (starting in December 1996) to agree a binding target for the reduction of CO₂ emissions. The United Kingdom has called for a 5–10 per cent cut by the year 2010⁷⁵. In order to help make progress with overarching CO₂ targets, it has been suggested that there should be a specific target for the transport sector⁷⁶. The Government do not consider that a sector-specific target is appropriate, stating: "the UK will continue to favour measures which achieve cost-effective savings, not only in the transport sector but across the whole community"⁷⁷. In order to limit CO₂ emissions from road vehicles, the United Kingdom Petroleum Industry Association (UKPIA) argued that "the last two decades have demonstrated that setting standards reduces pollution from road transport. There is no reason why this approach should not be effectively extended to include fuel efficiency" (p 418). Despite the undoubted success of regulations in reducing emissions of air pollutants, the Government argued that "regulation is not the appropriate policy instrument for reducing CO₂ emissions from vehicles" (Q 36). They currently prefer to concentrate on fiscal instruments (see 3.23–32).

3.12 A more flexible approach than a CO₂ emission limit would be to set a target for the average fuel consumption of the entire fleet, allowing for variations in the size and performance of different vehicles. This is the approach followed in the United States, where the Corporate Average Fuel Economy (CAFE) limit was established in 1978 in response to the United States' perceived dependence on imported oil. Table 6 illustrates the success of the CAFE regulations up to 1985, but it is a measure of the regulation's lack of success since then that there has been no improvement in either the CAFE standard or the actual fuel economy of domestically produced vehicles.

3.13 The Council of the Environment Ministers of the European Union recently adopted a similar proposal to reduce the emissions of CO₂ by the average new car to 120 grammes per mile by the year 2005. This is equivalent to fuel consumption of 5.0 litres per 100 km for a petrol engine car (57 mpg) and 4.5 litres for a car with a diesel engine (63 mpg)⁷⁸. The proposal contains an opt-out clause which states that the target can be delayed until 2010 if it proves too difficult to achieve by 2005. The SMMT opposes the Environment Council's target, warning that the car industry could face "a commercial disaster" if it is forced to provide cars which people do not want to buy. It argued that the Government should "create the environment in which customers want to downsize vehicles, are willing to sacrifice some performance for increases in fuel efficiency and are willing to do some walking about" (Q 367). Ford noted that if the target were applied today, it could only be met by a basic Ford Fiesta (Q 246).

⁷⁵ Department of the Environment Press Release, 2 July 1996.

⁷⁶ See for example the Royal Commission on Environmental Pollution, 18th Report, *ibid*, pp 44–45.

⁷⁷ Government Explanatory Memorandum on European Community Document 4188/96, *ibid*, (COM(95)689), paragraph 14.

⁷⁸ The Department of Transport estimates in *Transport Statistics Great Britain 1995* that the fuel consumption of the average 4-wheeled car in the United Kingdom between 1992 and 1994 was 9.1 litres per 100 kilometres.

Table 6—United States Corporate Average Fuel Economy(miles per United States gallon⁷⁹)

Year	CAFE standard	Domestic average fuel consumption
1978	18.0	18.7
1985	27.5	26.3
1994	27.5	26.3

Source: *Automotive Environment Analyst*, Issue 18, July 1996, p 21.

Voluntary agreement with industry

3.14 The European motor manufacturers have already committed themselves through their trade association ACEA to achieve a reduction in the average fuel consumption of a new car by around 10 per cent by the year 2005, which would leave consumption substantially higher than the Environment Council's target.

3.15 The European Commission issued a Consultation Document in July 1996 which addressed the methods by which CO₂ emissions from new cars could be reduced⁸⁰. The Commission proposals were based mainly on reaching a voluntary agreement with industry to reduce average CO₂ emissions from new cars by a set amount by a set year. It suggested a 25 per cent reduction by the year 2005 (base 1990) as a reasonable starting point, which is far higher than the manufacturers have so far volunteered (except those in Germany), but not substantial enough to meet the target set by the Environment Council. This would be supported by the introduction of fuel-economy labelling for new cars⁸¹, an increase in road fuel duties to prevent a fall in motoring costs as a result of improved fuel economy, and one or more other fiscal measures to promote more fuel-efficient passenger cars. Rover supported the 25 per cent target for petrol engine vehicles, but stated that it would be far more difficult to achieve with diesels (p 393).

3.16 In their response to these proposals the Government restated that they were unconvinced that the transport sector should be targeted specifically, and that it was necessary to reduce CO₂ emissions cost-effectively across all sectors. The Government supported the principle of voluntary agreements with industry. They added that responsibility for fiscal instruments must lie with Member States, but that they were pressing for a significant rise in the minimum excise rates for road fuels in the Member States, which are set by the Commission, in line with their policy of raising fuel excise duty each year in real terms. Overall, the Government welcomed the call for action, provided that the approach taken was cost-effective (p 4).

OTHER POLICY MEASURES

Harmonisation of standards

3.17 It is inevitable that in the early stages of development there will be several different specifications for the various alternative fuels and technologies. The issues which will have to be addressed include, inter alia, the composition of alternative fuels such as natural gas, liquid petroleum gas and biofuels and the recharging infrastructure for battery powered vehicles. United Kingdom standardisation work appears to be fairly well advanced, though international standardisation is progressing far more slowly. The DTI detailed the work of the various standard setting bodies for electric vehicles and gas vehicles (pp 175–6), and the European Biodiesel Board

⁷⁹ The United States gallon is equivalent to 0.833 Imperial gallons (or 3.785 litres).

⁸⁰ European Community Document 4188/96, *ibid.*, (COM(95)689).

⁸¹ This has been done in the United Kingdom since 1983 under Statutory Instrument No.1486 Passenger Car Fuel Consumption Order 1983.

stated that national organisations had defined standards for biodiesel, and that this work was being brought together to create an EU specification (p 312). The work on standardisation, especially in the field of electric vehicles, is being hampered by the lack of a clear front running technology. The Electricity Association concluded:

“It is important that standards are developed for electric vehicles, their components and infrastructure in order to minimise costs and ensure interchangeability and compatibility. At the same time, it is essential to avoid imposing unnecessary constraints on the development of cost-effective technological solutions” (p 298).

Direct action by government

3.18 There are several examples within the United Kingdom and internationally of local and national governments taking a lead in introducing alternatively powered vehicles. Within this country, for example, Oxford City Council, Westminster City Council and the London Borough of Camden have all conducted trials or pilot schemes involving alternative technologies. Oxford City Council have introduced a pilot scheme for an electric bus service between the railway station and the city centre (pp 177–8), Westminster City Council have trialled continuously regenerating particle traps and are exploring the possibility of using natural gas vehicles (pp 421–2) and the London Borough of Camden are using three electric and three gas powered vehicles as part of their Accessible Sustainable Transport Integration (ASTI) programme. Funding for the ASTI programme is provided by the local authority, the DTI, the European Commission (through its LIFE programme), and by public and private sector partners. Organisations involved include the Motor Industry Research Association, Powergen, Wavedriver, and Iveco Ford Truck Ltd. ASTI aims to “demonstrate practical ways of running integrated local accessible transport fleets with proper respect for the environment”⁸².

3.19 At the British International Motor Show in October 1996 the Secretary of State for Transport (Sir George Young MP) announced the launch of the Coventry Electric Vehicle Project. 14 Peugeot 106 electric cars and vans will be operated over a 12 month period in an attempt to create a viable operating model for other towns and cities. The programme will be co-funded by the Energy Saving Trust and will involve five local partners; Coventry City Council, Peugeot, East Midlands Electricity, PowerGen and Royal Mail Coventry⁸³.

Subsidy

3.20 Some witnesses argued that, at least in the short term, the Government should subsidise alternative vehicle technologies. This would bring environmental benefits as well as giving a boost to the manufacturers of such technologies (pp 81, 299, 398, 403). One example of such a scheme is in France, where the government and the nationalised electricity industry subsidise the purchase of electric vehicles; the manufacturer receives 10,000 francs and the consumer 5000 (p 60).

Zero emissions areas

3.21 Mr Bagshaw suggested that zero emissions areas could be established in inner cities with acute pollution problems, within which only zero (or perhaps very low) emission vehicles could operate (p 274).

Other factors

3.22 Some witnesses were concerned that the privatisation of the electricity industry might reduce investment in electric vehicle research and production: “Privatisation of the Electricity Industry could adversely affect the level of commitment to the development of electric vehicles” (p 79). The Government argued that the electricity companies had commercial incentives to invest in electric vehicles (Q 447), stating that “the privatisation of the electricity industry has had a

⁸² ASTI in Camden.

⁸³ Peugeot press release, 15 October 1996.

positive effect on the alternative fuels market. It has created new companies who have a need to be profitable and who acknowledge that diversification is the way forward" (p 176). The electricity companies themselves preferred not to comment.

TAXATION FRAMEWORK

3.23 The taxation framework can have a powerful influence on individual decisions. In the road transport sector, this can be seen by the successful encouragement of unleaded petrol by charging a lower rate of duty on it than on leaded petrol. The United Kingdom Government have stated that "economic instruments should have a bigger role to play in transport compared with direct regulation", arguing that they are cost-effective, flexible and provide an incentive for innovation⁸⁴. The ways in which the taxation system might be used to reduce emissions of air pollutants and CO₂ are examined in the following paragraphs. For reference, the total revenue raised from road vehicles by the United Kingdom Government in 1995-96 is shown in Table 7.

Fuel duty rates

3.24 All Member States in the European Union levy an extra tax on road vehicle fuels in addition to the standard rate Value Added Tax (VAT). At present the United Kingdom Government operates a system of variable fuel duty rates in which unleaded petrol is taxed more lightly than leaded petrol, and road fuel gases (natural gas and petroleum gas) are taxed more lightly than the liquid fossil fuels. These differentials are chiefly related to the control of air pollution; lead is a pollutant and super-unleaded contains higher levels of aromatics, including benzene. The fuel economy advantages of diesel are held to be balanced by uncertainties over its polluting effects, and duty is therefore now levied on it at the same rate as for unleaded petrol. Current fuel duty rates are set out in Table 8.

Table 7—Sources of Revenue from Road Vehicles 1995/96

Vehicle Excise Duty*	£4 billion
Fuel Duties*	£15.5 billion
VAT on vehicles (including VAT on road fuels)*	£6 billion
Tax on motor insurance premiums	£0.2 billion
TOTAL*	£26 billion

* rounded to nearest £0.5 billion

Source: HM Treasury (p 411).

Reduction in duty on alternative fuels

3.25 Many witnesses argued that fuel duty differentials could have an important effect on the type of fuel which consumers used by making certain fuels cheaper than others at the pump, even if they are actually more expensive to produce⁸⁵. In the November 1995 budget the Chancellor of the Exchequer made a 15 per cent cut in the duty payable on natural gas and liquefied petroleum gas, primarily for their emissions advantages.

3.26 The natural gas vehicle industry said that the purpose of the reduction in duty on gas fuels had been to achieve price parity for gases against petrol and diesel "at the pumps" (Q 310).

⁸⁴ *Transport—The Way Forward* (Cm 3234), pp 54-5.

⁸⁵ A similar conclusion was reached by the House of Lords Select Committee on Sustainable Development, in its Report in Session 1994-95 (HL Paper 72).

Compressed natural gas is now substantially cheaper than diesel, but this advantage is wiped out by the lower mileage achievable with gas (p 120). The NGVA welcomed the general strategy, but argued that in itself the reduction was not a sufficient incentive for private operators to invest in gas vehicle technology which might reduce pollution (pp 122–3). The Royal Mail stated that from their point of view “currently the stimulus for environmental initiatives is small” (p 402). Mr Parker of the NGVA said that “I have seen an increased level of interest from the bus operators and local authorities and some of the more commercially aware fleet operators [but] ... we are not seeing that interest translated into increased commitments” (Q 334).

Table 8—Current Fuel Duty Rates (correct as of July 1996)

Fuel	United Kingdom rate
Leaded petrol	39.12 pence per litre
Unleaded petrol	34.30 pence per litre
Super-unleaded petrol	37.62 pence per litre
Diesel	34.30 pence per litre
Road fuel gases	28.17 pence per kilogram

Source: HM Treasury (p 412).

3.27 The major problem identified was that although it was now approximately as cheap to run a vehicle on natural gas as it was to run it on petrol or diesel, the actual cost of buying a vehicle which could run on natural gas or of converting one to do so was still prohibitive. Both the NGVA and British Gas favoured a further reduction in the duty payable on gas, to at or near its EU minimum rate (eg. p 123) stating that:

“This is a sufficient differential to pay-back conversion costs of a typical fleet vehicle over its life-span and to provide an incentive to expand refuelling infrastructure” (p 120).

Mr Parker concluded that in the long run when the market increased in size economies of scale in the manufacturing process would reduce the price differential between gas and petrol or diesel vehicles and the duty differential might therefore also be reduced (Q 335).

3.28 Those involved in the production of biodiesel argued that a reduction in duty would encourage production and use of the fuel (Q 623, pp 312, 379). The BABFO noted that there was reduced fuel duty on biodiesel in Austria, France, Italy, the Czech Republic, Sweden and Germany (Q 621). In some countries financial incentives for biodiesel were also given. The European Biodiesel Board stated that “to date the UK Government has declined to give an exemption to any biodiesel product” (p 312). The Department of Transport argued that, considering the high production cost and exaggerated claims made about carbon savings, “biodiesel does not ... seem to offer a cost-effective environmental improvement at present” (p 14).

General increase in fuel duty rates

3.29 Several witnesses supported a general rise in fuel duty rates (pp 81, 141, 332, 352, 377). They argued that higher prices would discourage motorists from using as much fuel (reducing emissions of both air pollutants and of CO₂), and also that it would lead to more vehicle buyers demanding good fuel economy, creating a market-pull for the development of more fuel-efficient vehicles. The United Kingdom Government announced in 1993 that they would increase the rate of duty on fuel by at least five per cent above the rate of inflation each year; their major policy measure to make road transport contribute to the stabilisation of CO₂ emissions at 1990 levels by the year 2000.

3.30 Opinion in the oil and automotive industries split along predictable lines. The SMMT supported higher fuel duties, arguing "Fuel Excise Duties should be the primary CO₂ mechanism since they are the most cost-effective and least distorting measure" (p 141). The UKPIA did not support the current Government policy on fuel duties (p 418). The National Farmers' Union stated their concern that "the use of fiscal control could fail to recognise the dependence on road transport of rurally based industries" (p 379).

Circulation and purchase taxes

3.31 In many European countries the annual charge levied on road vehicles aims to reflect a vehicle's fuel efficiency and/or the amount of pollutants it produces. The criteria used include the size and power of the engine and the weight of the vehicle. In Germany the annual circulation tax has recently been altered from a system based on engine size to one based on both the fuel efficiency and emissions performance of vehicles. It is planned that the tax will be abolished altogether in 2003, with the money lost being recouped through higher fuel duties (see Appendix 6). In the United Kingdom the annual Vehicle Excise Duty (VED) is currently levied at a flat rate of £140 for all petrol or diesel passenger cars. Until this year electric vehicles were exempt. They are now charged at the reduced rate of £35, which the Electricity Association condemned as "a retrograde step" (p 299). Some countries also levy a purchase tax on vehicles in addition to VAT, which can be based on engine size (as in Belgium), fuel consumption (as in Austria) or pollution (as in Sweden). The United Kingdom does not currently levy an additional purchase tax on new vehicles.

Carbon tax

3.32 Some witnesses advocated the introduction of a carbon tax on all sources of CO₂ emissions. This would apply to road transport as it would to other sectors. The attraction of such a tax is that the market would ensure that the necessary adjustments could be made in the most cost-effective way. The drawback is that although it might be attractive in theory, it would prove very difficult to implement in practice⁸⁶.

RESEARCH PROGRAMMES

3.33 There are several government-industry research programmes aimed at improving vehicle technology, for example the Japanese Safety Car project and the Canadian Task Force on Cleaner Vehicles and Fuels. We will examine the approach taken by three of them: the American Partnership for a New Generation of Vehicles (PNGV); the European Union-wide Task Force on the Car of Tomorrow; and the United Kingdom's Foresight Vehicle project (along with other British research programmes).

(i) Partnership for a New Generation of Vehicles (PNGV)

3.34 The PNGV is a collaborative programme between the three major car manufacturers in the United States (General Motors, Ford and Chrysler) and the federal government. It was established in 1993 with three main aims: to improve national competitiveness in manufacturing; to implement commercially viable innovations; and to develop vehicles that can achieve up to three times the fuel efficiency of comparable American 1994 family sedans.

3.35 In the early stages a wide range of projects was supported, with a narrowing of effort to take place in 1997 and again in 2000 based on the performance of the technologies against defined objectives for safety, emissions performance and PNGV goal 3 (improved fuel economy). Prototype vehicles should be produced by the year 2004. The PNGV Review Committee's second report (1996) stated that there were three promising candidates which might achieve PNGV goal 3. The first was the direct injection compression ignition (diesel) internal combustion engine; "currently the most promising candidate" within the PNGV timescale. The second was the fuel cell

⁸⁶ The House of Lords Select Committee on the European Communities has investigated the carbon tax, particularly in its 8th Report (1991-92), *Carbon/Energy Tax*, (HL 52); and most recently in its 17th Report (1994-95), *European Union Energy Policy* (HL 87).

vehicle, which was considered to have high potential but was the least developed of the options. The Review Committee concluded that the fuel cell would probably require a further 10 to 15 years' development before it could be mass produced efficiently. The third option was the gas turbine. The Review Committee envisaged that all of the three drivetrains would be used in conjunction with an energy storage device such as a battery, flywheel or ultracapacitor⁸⁷.

(ii) Task Force on the Car of Tomorrow

3.36 The Task Force on the Car of Tomorrow is one of seven Task Forces which have been established by the European Union to co-ordinate research into specific areas across its various funding programmes. It was set up in 1995, and is therefore less advanced than the PNGV. In the short to medium term, the Task Force aims to identify and encourage on to the market very clean internal combustion engine vehicles. In the longer term it is targeting zero or negligible emission vehicles which are capable of exploiting renewable resources⁸⁸. Under the terms of the plan the Task Force has drawn up safety, energy consumption and emissions performance targets in a similar manner to the PNGV. It considers that "there is currently no propulsion technology which emerges as the most energy efficient in all circumstances", and will therefore support a range of technologies in pursuit of their defined objectives. The Task Force is in the process of identifying priority areas for research, and will encourage the development of partnerships involving large and small companies and public authorities, and will attempt to accelerate the transfer of research into the market place. One of the major features of the programme will be a comprehensive analysis of the different technologies. The resources available to Car of Tomorrow projects are far lower than under the American PNGV, at 80–100 million ecus (c. £64–80 million) per year compared to around 300 million ecus per year (c. £240 million) for the American programme (the European figure does not include research programmes sponsored by national governments) (Q 706).

(iii) Foresight Vehicle project

3.37 The Foresight Vehicle project was established as a result of the Technology Foresight Report on Transport. This Report recommended that three projects be established; the informed traveller, concentrating on the provision of transport information; the clear zones project, examining traffic flows; and the Foresight Vehicle project, aimed at on-vehicle technology. The DTI commented that one of the key messages emerging from the Technology Foresight Report on Transport was the need for "a more effective partnership between all the different players involved; universities, research establishments, vehicle manufacturers, design houses, component suppliers and government" (Q 440). This call was strongly echoed by the Motor Industry Research Association (MIRA) and by the manager of the Foresight Vehicle project, Professor Cernes, who spoke of the importance of discovering "new ways of working such that UK manufacturing industry can respond rapidly to new technology and consequent changes in customer demand" (p 193).

3.38 Professor Cernes is also the manager of a complementary initiative launched by the Engineering and Physical Sciences Research Council (EPSRC); the Innovative Manufacturing Initiative (IMI) for Road Vehicles. This will concentrate on vehicle structures, in-vehicle telematics and supply chain re-engineering. He stated that both programmes were concerned with improving the United Kingdom's industrial competitiveness and the quality of life, and that these goals were dependent on the "ability to disseminate the research outcomes and industry's ability to exploit them" (p 193). The total budget for the IMI for Road Vehicles was expected to be around £33 million between 1995 and 1997, of which industry would supply £26 million, and the total budget for the Foresight Vehicle project was expected to be £30–£40 million over three years, of which industry would contribute around half (Q 503). The DTI and the EPSRC also run fuel cell development programmes which provide funding for industrial and university-led research on both solid polymer and solid oxide type fuel cells.

⁸⁷ Review of the Research Program of the Partnership for a New Generation of Vehicles, 2nd Report (1996).

⁸⁸ European Community Document 6022/96, *Car of Tomorrow Action Plan* (SEC(96)501).

UNITED KINGDOM RESEARCH POLICY

3.39 All witnesses who mentioned the subject agreed on the need for governments to contribute to the funding of automotive research in collaboration with industry, especially long term research which industry alone was ill-equipped to undertake (eg. pp 94, 140). In contrast to this consensus, there were several differing views on the potential of the United Kingdom economy to take advantage of the development of new vehicle technologies. The SMMT argued that the United Kingdom was well suited to the development and exploitation of new types of conventional mass produced vehicles, but that "for alternative technologies the UK is not so well placed" (p 140). Dr Davies and JCB Research both argued the opposite; that "the development of low emission vehicles is ... unusually well suited to the UK's current strengths", but that capacity for exploiting new mass produced vehicles was poor (pp 295, 357). The argument centred on whether the large foreign owned car manufacturers would use the United Kingdom to produce technologically innovative vehicles on a large scale or whether such pre-production research and development was likely to be undertaken elsewhere. The SMMT stated that "the United Kingdom has in recent years experienced what may be unprecedented levels of automotive investment" (p 140). The European Commission noted that the Japanese-owned car companies usually carried out their longer term research and development, for example on fuel cells, in Japan. The Royal Academy of Engineering and the European Commission considered that in general the United Kingdom's potential in the automotive sector was poor (pp 243, 398).

3.40 Despite the establishment of the IMI for Road Vehicles and the Foresight Vehicle project, the SMMT argued that "the national co-ordination of research into new technologies can best be described as weak and fragmented" (p 139), adding "there is a vast amount of excellent research going on in universities. The exploitation of that research is a national problem" (Q 385). Several other witnesses, including the Minister for Science and Technology, Mr Ian Taylor MP, agreed on the existence of what MIRA described as "a science and technology lead in the UK but an exploitation lag" (QQ 497, 730, pp 79-80, 92, 243, 355, 376).

3.41 One of the principal problems identified was that "too many component manufacturers are not carrying out enough research and development work" (Q 440, p 243)⁸⁹. The Royal Academy of Engineering considered that, since the British motor industry had now come under foreign ownership, it was likely that "the next step will be that all first tier suppliers will be foreign owned" (p 398). It was crucial that British companies became more pro-active in searching for new products to develop and sell, rather than waiting for new specifications from the big automotive firms. MIRA argued that there was insufficient communication between the "actors" involved in the United Kingdom automotive sector, and that more specifically the integration of new technologies would require the re-engineering of the supply network to include organisations which had previously not been involved at all (QQ 268, 273). Two of the scientists involved in fuel cell research stated that the Government needed to identify and somehow pull together the large number of people who could develop fuel cell technology (Q 121). Professor Cernes confirmed that this was what the Foresight Vehicle project and the Innovative Manufacturing Initiative were seeking to do; "we are looking to hunt in packs on the global supply market" (Q 524).

3.42 Foresight Vehicle will be organised in thematic groups, with the aim of identifying priority research areas with potential for developing attractive products. Ricardo is the leader of the engine group. Mr Monaghan of Ricardo outlined the problems associated with bringing one of these groups together:

"Regrettably we have been unable to attend as many of the meetings as we would like. In fact, we have found it rather difficult to get any form to the engine side of the programme because the funding is unclear" (Q 415).

He went on to state that a great deal of effort was required to put together a bid for United Kingdom Government or European Union funding, with only a small chance of success (Q 416).

⁸⁹ See also *The Guardian*, 25 September 1996.

CHAPTER 4 OPINION OF THE COMMITTEE

INTRODUCTION

4.1 We are more optimistic about the ability of technology to address successfully the problem of air pollution than we were when we began this enquiry. Great strides have already been made with the development and introduction of less polluting vehicles and cleaner fuels. This does not mean that further measures will not be necessary, but the outline of those measures has been identified and they can and should be implemented over the coming years as part of overall strategies aimed at improving air quality across all sectors⁹⁰. One of the most effective ways of reducing all emissions, both air pollutants and CO₂, is through improving fuel economy. In the short term incremental improvements to internal combustion engine vehicles and petrol and diesel fuels will be the most important method of reducing air pollution from road vehicles. Alternative fuel and vehicle technologies can also make a substantial contribution to improving air quality. However, we are far less optimistic about the prospect that on-vehicle technology will contribute to a reduction in CO₂ emissions from road vehicles. In the short term the fuel consumption of internal combustion engine vehicles should be improved. Steps which could be considered for achieving greater fuel economy include reducing the weight of vehicles, discouraging the manufacture of cars with large capacity engines and reducing the speed limit on motorways. For the long term research must continue into technologies which can make use of renewable sources of energy or use substantially less fossil fuel. The taxation system should be readjusted to discourage fossil fuel consumption and to encourage fuel efficiency. With an integrated approach to road transport policy and firm action taken to introduce new technology, it is possible to maintain many of the benefits that road vehicles bring, while reducing the environmental and health impacts.

4.2 Co-operation between countries is an essential element in the campaigns against air pollution and global warming. It is true that the effects of air pollution are primarily local, but some pollutants such as ozone and acid rain do cross national borders. Furthermore, the automotive and oil industries are international and measures introduced in one country or area might have a serious effect on economic competitiveness if they were not followed elsewhere. CO₂ especially is a global problem in that its effect once in the atmosphere is the same wherever it is emitted. Acting on its own the United Kingdom cannot substantially influence atmospheric levels of CO₂, and so must take part in the development of international action such as the European Union Environment Council's proposed fuel consumption target⁹¹.

THE SHORT TERM

4.3 We welcome the new emissions limits for new vehicles which have been proposed by the European Commission (see 3.3), and hope that they will be as successful in stimulating the development of new technology as the Stage I and II limits. It is important that there should be no prevarication at this stage; investment must be supported by the certainty that stricter emission limits for which the new technology will be required will be introduced by a specified date. **We recommend that the Government seek to bring about agreement on the Stage III and Stage IV emissions limits as soon as possible, so that industry is given a clear target.**

4.4 We are concerned that the testing cycle currently used in the European Union does not give an accurate indication of the true performance of vehicles on the roads, thus undermining its validity (see 3.6). Not only does this make it more difficult to predict future air quality, it also hampers attempts to compare the real emissions from a petrol or diesel vehicle with, for example, the emissions from a power station during the production of enough electricity to power an electric vehicle over the same distance. **We recommend that the Government seek to have the**

⁹⁰ The United Kingdom programme is based on the *United Kingdom National Air Quality Strategy* (August 1996), co-ordinated by the Department of the Environment and the Scottish Office. Table 1 (Chapter 1) outlines the pollution caused by domestic and industrial activities in addition to the road transport sector.

⁹¹ The Environment Council has proposed that the average fuel consumption for new cars should be 5.0 litres per 100 km for a petrol vehicle (57 mpg) and 4.5 litres per 100 km for a diesel vehicle (63 mpg) by the year 2005 (or 2010 if 2005 is unfeasible) (see 3.13).

European Union testing cycle amended so that it more accurately reflects average European ambient temperatures and driving patterns.

4.5 In the short term the consumption of fossil fuels by internal combustion engine vehicles can be reduced by a range of measures including lean-burn systems for petrol engines and electronic engine management systems for both petrol and diesel engines. However, the evidence suggests that reducing the weight of the vehicle may be more effective in reducing fuel consumption and hence CO₂ emissions. While the introduction of smaller and lighter cars may help to reduce total fuel consumption, this will not offset the effect of the continuing increase in the number of vehicles.

4.6 During the course of our enquiry we have received much evidence on the question of sulphur in petrol and diesel fuels. In addition to being a pollutant itself, sulphur can also poison advanced pollution control equipment. The Committee, along with many of our witnesses, was disappointed that the proposed European Union fuel standards for the year 2000 set the maximum permitted sulphur level for petrol and diesel at well above the level which the automotive industry considers is necessary for the development and application of advanced pollution control devices (see 2.10, 2.14, 2.19–21). We are particularly concerned that the lack of widely available very low sulphur fuel (less than 50 parts per million) will not only forestall the introduction of anti-pollution devices for both diesel and lean-burn petrol engine vehicles, but will also affect the timescale of their development. We accept that the additional investment necessary for the oil industry will be significant (at around 35–40 billion ecus (c. £28–£32 billion)), but in terms of ecus per litre, the actual additional cost to the motorist will be far smaller than the regional variations in price which currently exist between, for example, London and East Anglia. The Committee considers that the amount of sulphur in petrol and diesel can and should be reduced to below the levels which have already been proposed. **The United Kingdom Government should vigorously promote an alteration to the proposed European Union fuel standards for the year 2000, reducing the maximum permitted sulphur content for both petrol and diesel fuels to 50 parts per million. Further reductions should also be considered for the future⁹².**

4.7 The Committee received mixed evidence on the potential of fuel additives to reduce pollution. Fuel additives may have the potential to reduce emissions of air pollutants from road vehicles before alternative technologies become available. We were concerned to learn, however, that a proposed new fuel additive is not required to go through an approval process at either a national or European level. Previous experience with additives, for example lead, indicates that the onus should be on those who propose to use fuel additives to prove that their fuel is safe. **We recommend that the Government, in conjunction with the European Union and other Member States, should ensure that new fuel additives have been fully tested for safety before introduction to the market.**

4.8 There is a trade-off between the need to produce less polluting, more fuel-efficient vehicles and the need to get them into the market place. Vehicles conforming to Stage III and Stage IV legislation will be substantially less polluting than vehicles produced before 1992, when the Stage I limits were introduced, but they will also be relatively more expensive. There is a danger that the increased cost of new less polluting vehicles will delay their introduction into the vehicle fleet unless means are found to encourage them. This concern has been exacerbated by the evidence of the ageing of the United Kingdom vehicle fleet.

4.9 In Chapter 3 we outlined some of the plans proposed to tackle this problem. The automotive industry and the AA suggested a scrappage scheme, in which a financial incentive would be given to scrap old vehicles and thus remove them from circulation entirely. Such a scheme would be administratively complex, but would still be a blunt instrument as emissions from vehicles depend not only on the age of the vehicle but partly on the make and partly on the state of

⁹² A tax concession would assist in the early introduction of very low sulphur fuels, such as the "City Diesel" sold in, for example, Sweden and parts of London (see 4.19).

maintenance. The actual level of pollution coming from a vehicle could not itself be made the criterion for a handout because it could reward the drivers of those vehicles which are very poorly maintained. Scrappage schemes do not appear to be a practical means of reducing air pollution from road vehicles in the United Kingdom.

4.10 The Government have announced that for existing vehicles they will concentrate their effort on the enforcement of emissions standards for all vehicles, both at the annual test and in random roadside checks⁹³. The new emissions check at the annual vehicle test and the introduction of roadside testing will ensure that the existing fleet makes a contribution to the necessary reduction in air pollution. **The Committee endorses the Government's policies to test emissions from the existing vehicle fleet, and recommends their early implementation.**

4.11 **The Committee further recommends progressively tightening the standards required for the existing fleet.** This will have a directly beneficial result by cleaning up vehicle emissions, and may cause the scrapping of more polluting vehicles where it is uneconomic to bring them to the required standard. A reasonable lead time would have to be given which would give the market time to adjust—the second hand value of older models which were unlikely to meet the new standards would fall to take account of the new standards. If a vehicle failed an emissions test because the test had become more severe, the owner should not be forced to take it off the road immediately but should be given time, perhaps three months, to repair or replace the vehicle, or to run it on cleaner fuels to reduce its emissions⁹⁴. To avoid creating an international trade in grossly polluting cars, it would be desirable to have some international co-ordination. **We recommend that a "minimum acceptable emissions standard" for each class of vehicle⁹⁵ over three years old be set up on a European-wide basis and that this be reviewed regularly to mirror regulations introduced for new vehicles.**

4.12 We have stated that developments in the field of petrol and diesel powered internal combustion engines will continue to be the most important factor in emissions reduction for many years. However, alternative technologies can—if properly targeted—make a worthwhile contribution to improving air quality. (They will not make a substantial contribution to reducing emissions of CO₂ from the road transport sector until they come into very widespread use.) Furthermore, if a start is not made on developing alternative technologies now, they will not be in a position to make greater contributions in the longer term. If vehicle numbers continue to increase, alternative technologies will have a key role to play. In the short term compressed natural gas, liquefied petroleum gas and battery electric vehicles could have an immediate impact on reducing urban air pollution. Similar conclusions have been drawn by previous studies⁹⁶, but to little effect in terms of getting the alternatives into actual use. Urban depot-based vehicles are particularly suited to adopt these alternatives; for such fleets many of the infrastructural problems identified with the introduction of new fuels or new propulsion technologies are relatively easy to overcome.

4.13 Government departments and local authorities should use their power as fleet operators and contractors of services to take a lead in this action, and we commend those which have already done so. **We recommend that Government departments and local authorities switch to gas or electric vehicles where appropriate to give an initial impetus to alternative power.** The resulting orders for alternative power technologies may also boost small British companies, giving them a home market on which to base future exports. Large scale tests could also enable the new technologies to be evaluated. It is important that the results of tests and pilot schemes are compiled and continually updated and made widely available. We commend the Government for commissioning the Energy Technology Support Unit desk-top study on alternative fuels and the

⁹³ *National Air Quality Strategy, ibid*, p 52.

⁹⁴ The AA stated that in the United Kingdom 50 per cent of road vehicle-related pollution was caused by just 10 per cent of the vehicles (Q 605).

⁹⁵ The classes of vehicle should be the same as those already used for emissions limits on new vehicles.

⁹⁶ eg. Royal Commission on Environmental Pollution, 18th Report, *ibid*.

continuing field trials. **We recommend that the Government establish means for information exchange with local authorities, private fleet operators and the vehicle industry itself.**

4.14 Those involved in such schemes do take a risk, however. In the early years the alternative technologies will probably cost more than their petrol and diesel powered equivalents. There is a need to spread the extra effort and cost, and we therefore strongly support the establishment of further collaborative programmes such as the Camden Accessible Sustainable Transport Integration (ASTI) project, which could be used as a blueprint for further larger collaborations. The Government should put potential partners in touch with each other.

4.15 Encouraging local authorities and government departments to take a lead is one way of focusing on those areas which will make the most difference. Another way is to target those vehicles which are often the most polluting in the most environmentally sensitive areas. Urban taxis and buses are two obvious examples. They have high mileage in urban areas, many have old diesel engines which can be very polluting, and the necessary infrastructural adjustments could be made at lowest cost. Buses especially have set routes and refuel at a limited number of sites. **The Committee recommends that the Government should introduce a scheme to give financial incentives to taxi owners and bus and other fleet vehicle operators to replace their vehicles with gas powered or electric vehicles.**

4.16 It is illogical that electric vehicles are not required to undergo a regular safety and performance test. We accept that regulations may be difficult to draw up due to the variety of vehicles on the roads, but certain features such as brakes could and should be checked in an annual test. This might also reassure potential users that road vehicles are safe. **The Government should introduce an MOT test for electric vehicles.**

4.17 The Committee considers that, where possible, the taxation system should be designed to encourage the most environmentally desirable outcomes. The measures we recommend should be considered as a package; overall their effect is intended to be tax neutral. The United Kingdom Government has already begun to apply environmental criteria to some of the taxes applied to road vehicles, for example with the introduction of a reduced fuel duty on unleaded petrol (see 3.24). The differential in cost was very effective in promoting the use of unleaded petrol. Similar differentials should be used to benefit other fuels which have proven advantages in terms of emissions when compared to standard petrol and diesel fuels.

4.18 The use of natural gas and liquid petroleum gas in internal combustion engines substantially reduces emissions of air pollutants. A reduction in duty for these fuels would recompense the extra cost of converting vehicles to gas or of buying dedicated gas vehicles, and therefore encourage the uptake of gas-powered vehicles. We commend the Government for taking a first step and reducing the duty on gaseous fuels in the 1995 budget, and **we recommend that the duty on natural gas and petroleum gas be reduced to the European Union minimum of 7.8 pence/kg immediately.**

4.19 The Committee has recommended that very low sulphur fuel (less than 50 parts per million) should be made compulsory in this country by the year 2000 because sulphur is a pollutant and reduces the effectiveness of pollution control equipment on vehicles (see 4.6). **The Government should reduce the duty payable on very low sulphur fuels now in order to establish a market before 2000 and ease the process of transition for both motorists and oil companies.**

4.20 Biofuels naturally have a very low sulphur content. With current technology⁹⁷ biofuels are likely to have a limited application for road vehicles, but they do offer lower emissions than fossil fuels and may have some useful niche applications. **The Government should reduce the fuel duty payable on biofuels.**

⁹⁷ See 2.32.

4.21 In order to balance the resulting reduction in Government revenue, **the revenue which is lost through the reduced fuel duty rates should be recouped through raises in the fuel duty on standard petrol and diesel fuels**, which the Government is in any case committed to doing by at least 5 per cent above the rate of inflation each year. This would also increase the differentials in price with other fuels.

4.22 More energy and resources are used up during a vehicle's operational lifetime than in its manufacture⁹⁸. If the taxation system does not reflect this, it will not raise revenue in the most environmentally efficient way. For example, the annual Vehicle Excise Duty is applied irrespective of the fuel consumed or the air pollution caused by individual vehicles. In contrast, fuel duty addresses the root cause of the problem; the combustion of hydrocarbon fuels which produces air pollution and CO₂. **The Committee recommends that Vehicle Excise Duty be abolished for private and light goods vehicles with less than 1500 cc⁹⁹, and that fuel duty rates be increased to recover the lost revenue.**

4.23 This one-off reorganisation of the taxation system would focus attention on the need to conserve fuel and would also help to stimulate demand for more fuel efficient vehicles. Unlike regulatory solutions such as mandatory fuel consumption limits for new vehicles, this approach would encourage rather than depress sales of new vehicles. Furthermore, it would not prescribe to the market what solutions should be found; the desired outcome would be reached in the most cost-effective way.

4.24 It is important that, whatever the merits of these policies on environmental grounds, British firms and individuals are not put at a disadvantage in relation to those from other countries. It is therefore desirable that the Government should seek to co-ordinate their action with the other Member States of the European Union. One way of proceeding would be annual rises in the European Union's minimum fuel duty rates for petrol and diesel and we support the Government's efforts in this area (see 3.16).

THE MEDIUM AND LONG TERM

4.25 Internal combustion engines—The massive research effort into developing further the internal combustion engine will continue; while air pollution is now firmly in the spotlight, ways must be found to make equal efforts to reduce fuel consumption. However, carmakers consider that further investment to reduce emissions of air pollutants will produce diminishing returns, and Ford stated that the direct injection four valve per cylinder diesel engine was "close to the theoretical limit of efficiency" for an internal combustion engine (p 74).

4.26 Alternative fuels—The use of fuels such as natural gas, petroleum gas and biodiesel in the internal combustion engine is well understood and there appears to be limited scope for further research in this area. As we have outlined, it is more important to encourage the application of these technologies. Away from the engine itself, one area which may be important for the production of fuels from renewable resources is research into plants, possibly using genetic engineering, to increase the amount of fuel which can be produced and to reduce its cost. Another important issue is that of gas storage on board vehicles. If a way can be found to store gas conveniently, safely and cheaply it may be possible to extend the use of gaseous fuels in cars and to adapt the technology to hydrogen. This could assist the introduction of fuel cell powered vehicles. **We recommend that research into gas storage on board vehicles should be supported as a priority.**

⁹⁸ Ford research indicates that over a vehicle's life-cycle production accounts for 10 per cent of the energy used and vehicle usage accounts for 90 per cent (p 89). Research at the UPI institute in Heidelberg indicates that one quarter of a vehicle's CO₂ emissions take place in the production and dismantling process (*Automotive Environment Analyst*, no. 18, July 1996, p 21).

⁹⁹ Approximately 9 million private and light goods vehicles fell into this category in 1995, or approximately 40 per cent of the total number of private and light goods vehicles (Department of Transport, *Vehicle Licensing Statistics: 1995* (July 1996), p 19).

4.27 Other combustion engines—There will probably be considerable progress in such technologies, particularly gas turbines. However, it is unlikely that any of them will overtake the internal combustion engine in terms of cost, emissions of air pollutants and fuel efficiency, particularly as some improvements in the performance of the internal combustion engine remain to be made.

4.28 Hybrid Vehicles—Hybrid vehicles possess more than one power source; including at least one energy generator, such as an internal combustion engine, and one energy storage device, such as a battery. The presence of two different systems inevitably increases the weight, cost and complexity of hybrid vehicles. Hybrids do, however, offer some potential to reduce both emissions of air pollutants and fuel consumption. Over short distances a hybrid vehicle can draw energy from the storage device and will therefore have zero emissions of pollutants; an advantage in congested urban areas. The storage device can subsequently be recharged by the energy generator. The storage device can also be used to smooth out peak power demands on the energy generator by providing extra power to the wheels when necessary, which reduces fuel consumption. Hybrid vehicles could have a role to play in reducing air pollution (particularly in urban areas) and fuel consumption in the medium term, and in developing new technologies in the longer term.

4.29 Chemical batteries and other energy storage systems—Given the length of time research into battery powered vehicles has been going on, we are not optimistic that chemical batteries will be able to compete with the internal combustion engine without a dramatic technological breakthrough. In any case, little of the groundbreaking battery research for road vehicles is going on in the United Kingdom. The latest development—the lithium-ion battery—has taken place in Japan. The evidence similarly indicates that it is unlikely that flywheels, ultracapacitors or other storage devices will be able to carry enough energy to give a full size vehicle an acceptable range. All of these technologies may well have an application as a secondary energy storage device to even out power demands on the primary device and take advantage of regenerative braking. Some of the most successful research into electric vehicles has been away from the battery itself (for example in lightweight electric motors), and this technology is applicable to fuel cell vehicles.

4.30 Fuel cells—Many witnesses were very optimistic about the potential of fuel cells to compete with the internal combustion engine, and much of the evidence was highly encouraging. While the pace of development appears to be rapid, and despite what some of our witnesses implied, we consider that further basic research is still needed to bring about substantial improvements in fuel cell performance. The fuel cell also needs developments to reduce cost, but it has the potential to become the chosen power source for vehicles in the future and the United Kingdom must not miss out on such a major opportunity. We were concerned, therefore, at the lack of emphasis given to fuel cell research in the Technology Foresight Report on Transport. **Fuel cell research should be strongly supported on a national basis, concentrating in particular on maintaining cell efficiency while reducing the cost and facilitating the mass production of components.**

4.31 The production and distribution of fuel is a key issue. If the fuel cell can compete with the internal combustion engine on a technical and cost basis, the question of a new hydrogen production, distribution and storage infrastructure will become crucial. This question will only be resolved if a new way of thinking is adopted. The great attraction of hydrogen as a fuel is that it burns to water rather than CO₂. This advantage disappears if fossil fuels are used to manufacture the hydrogen because CO₂ is still produced. A truly sustainable form of hydrogen production would be from solar energy. Research into cheap and efficient photovoltaic cells would assist the large-scale production of hydrogen through electrolysis. Similarly, the use of enzymes to generate hydrogen directly from renewable biomass may be an important development¹⁰⁰. The use of nuclear energy to produce hydrogen may have to be considered if the problem of global warming continues to prove intractable. Some of the distribution and storage issues may be resolved with

¹⁰⁰ *New Scientist*, 6 July 1996.

the aid of experience gained from using compressed natural gas as a vehicle fuel. **Research into ways of producing hydrogen from sustainable resources should be given priority, especially in view of the many wider applications this might have.**

4.32 Clean and efficient vehicle and fuel technologies will grow in importance over the coming years. The lack of clear front runners in many of the races to design environmental products—for example in the short term a De-NO_x catalyst and in the long term a dramatically more fuel efficient powertrain—means that there currently exist real opportunities for new and innovative products. The degree of competition means that these opportunities are unlikely to exist for very long.

4.33 There are several national programmes in the United Kingdom which help companies to carry out automotive-related research market. The most important are outlined in 3.37-38. The European Union's Car of Tomorrow programme will also examine new propulsion unit technology. Given the limited resources available to these programmes, their efforts should not be spread too widely; the Manager of the United Kingdom Foresight Vehicle programme stated that it would be necessary to identify a small number of priority areas for research (Q 512). **The internal combustion engine has already benefited from massive investment by vehicle manufacturers, and this will continue, partly in response to legislation aimed at reducing emissions of air pollutants from vehicles. The programmes which are partly funded by public money should, therefore, concentrate on the long term development of alternative technologies which have high potential to reduce fossil fuel consumption. Fuel cells appear to be the most promising technology and United Kingdom and European research programmes should concentrate on their development. The Government should initiate a national demonstration project with a United Kingdom-based vehicle manufacturer. Research should also be conducted into the sustainable production of hydrogen as fuel for the fuel cell and into the storage of hydrogen on board vehicles.**

CHAPTER 5 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

5.1 We recommend that the Government seek to bring about agreement on the Stage III and Stage IV emissions limits as soon as possible, so that industry is given a clear target. (paragraph 4.3)

5.2 We recommend that the Government seek to have the European Union testing cycle amended so that it more accurately reflects average European ambient temperatures and driving patterns. (paragraph 4.4)

5.3 The United Kingdom Government should vigorously promote an alteration to the proposed European Union fuel standards for the year 2000, reducing the maximum permitted sulphur content for both petrol and diesel fuels to 50 parts per million. Further reductions should also be considered for the future. (paragraph 4.6)

5.4 We recommend that the Government, in conjunction with the European Union and other Member States, should ensure that new fuel additives have been fully tested for safety before introduction to the market. (paragraph 4.7)

5.5 The Committee endorses the Government's policies to test emissions from the existing vehicle fleet, and recommends their early implementation. (paragraph 4.10)

5.6 The Committee further recommends progressively tightening the standards required for the existing fleet. (paragraph 4.11)

5.7 We recommend that a "minimum acceptable emissions standard" for each class of vehicle over three years old be set up on a European-wide basis and that this be reviewed regularly to mirror regulations introduced for new vehicles. (paragraph 4.11)

5.8 We recommend that Government departments and local authorities switch to gas or electric vehicles where appropriate to give an initial impetus to alternative power. (paragraph 4.13)

5.9 We recommend that the Government establish means for information exchange with local authorities, private fleet operators and the vehicle industry itself. (paragraph 4.13)

5.10 The Committee recommends that the Government should introduce a scheme to give financial incentives to taxi owners and bus and other fleet vehicle operators to replace their vehicles with gas powered or electric vehicles. (paragraph 4.15)

5.11 The Government should introduce an MOT test for electric vehicles. (paragraph 4.16)

5.12 We recommend that the duty on natural gas and petroleum gas be reduced to the European Union minimum of 7.8 pence/kg immediately. (paragraph 4.18)

5.13 The Government should reduce the duty payable on very low sulphur fuels now in order to establish a market before 2000 and ease the process of transition for both motorists and oil companies. (paragraph 4.19)

5.14 The Government should reduce the fuel duty payable on biofuels. (paragraph 4.20)

5.15 The revenue which is lost through the reduced fuel duty rates should be recouped through raises in the fuel duty on standard petrol and diesel fuels. (paragraph 4.21)

5.16 The Committee recommends that Vehicle Excise Duty be abolished for private and light goods vehicles with less than 1500 cc, and that fuel duty rates be increased to recover the lost revenue. (paragraph 4.22)

5.17 We recommend that research into gas storage on board vehicles should be supported as a priority. (paragraph 4.26)

5.18 Fuel cell research should be strongly supported on a national basis, concentrating in particular on maintaining cell efficiency while reducing the cost and facilitating the mass production of components. (paragraph 4.30)

5.19 Research into ways of producing hydrogen from sustainable resources should be given priority, especially in view of the many wider applications this might have. (paragraph 4.31)

5.20 The internal combustion engine has already benefited from massive investment by vehicle manufacturers, and this will continue, partly in response to legislation aimed at reducing emissions of air pollutants from vehicles. The programmes which are partly funded by public money should, therefore, concentrate on the long term development of alternative technologies which have high potential to reduce fossil fuel consumption. Fuel cells appear to be the most promising technology and United Kingdom and European research programmes should concentrate on their development. The Government should initiate a national demonstration project with a United Kingdom-based vehicle manufacturer. Research should also be conducted into the sustainable production of hydrogen as fuel for the fuel cell and into the storage of hydrogen on board vehicles. (paragraph 4.33)

EGR	Exhaust Gas Recirculation
EPAQS	Expert Panel on Air Quality Standards
EPSRC	Engineering and Physical Sciences Research Council
ETBE	Ethyl Tertiary Butyl Ether
ETSU	Energy Technology Support Unit
EU	European Union
EV	Electric Vehicle
EVA	Electric Vehicle Association
HC	Hydrocarbons
IMI	Innovative Manufacturing Initiative
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt (10 ³ W)
kJ	Kilojoule (10 ³ J)
LEV	Low Emission Vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LPGA	Liquid Petroleum Gas Association
M100	Pure methanol (M85 with 15 per cent petrol added)
MIRA	Motors Industry Research Association
MP	Member of Parliament
MTBE	Methyl Tertiary Butyl Ether
NERC	Natural Environment Research Council
NGV	Natural Gas Vehicle
NGVA	Natural Gas Vehicle Association
NiCd	Nickel-Cadmium (battery type)
NOx	Nitrogen oxides
O ₃	Ozone
OECD	Organisation for Economic Co-operation and Development
PAPC	Phosphoric Acid Fuel Cell
PAH	Poly-Aromatic Hydrocarbon
PEMFC	Proton Exchange Membrane Fuel Cell
PM	Particulate matter
PM10	Particulate matter of 10 micrometres diameter or less
PM2.5	Particulate matter of 2.5 micrometres diameter or less
PNQV	Partnership for a New Generation of Vehicles (in the USA)
POST	Parliamentary Office of Science and Technology
ppm	parts per million
QUAAR	Quality of Urban Air Review Group
RCEP	Royal Commission on Environmental Pollution
RMF	Rape methyl ester (bio-diesel)

APPENDIX 1

Sub-Committee II: Towards Zero Emissions for Road Transport

The members of Sub-Committee II were:

L. Dixon-Smith (Chairman)
L. Kirkwood
L. Lewis of Newnham
L. Nathan
L. Perry of Walton
L. Porter of Luddenham
L. Redesdale
E. Selborne
L. Soulsby of Swaffham Prior
L. Vinson
L. Walton of Detchant

The Sub-Committee appointed as its Specialist Adviser Professor Nigel Bell of the Imperial College of Science, Technology and Medicine.

APPENDIX 2

Acronyms

AA	Automobile Association
A21	An alternative fuel based on naphtha
ACEA	European Auto-Constructors' Association
AECC	Automobile Emissions Control by Catalyst
ASTI	Accessible Sustainable Transport Integration Project
BABFO	British Association of Bio Fuels and Oils
CAFE	Corporate Average Fuel Economy (in the USA)
CDTI	Clean Diesel Technologies Inc. (USA)
CNG	Compressed natural gas
CO	Carbon monoxide
CO ₂	Carbon dioxide
COMEAP	Committee on the Medical Aspects of Air Pollution
CRT	Continuously Regenerating Trap
DME	Di-methyl ether (an alternative fuel)
DTI	Department of Trade and Industry
E10	10 per cent ethanol in petrol (sold in the USA as gasohol)
E100	Pure ethanol (E85 with 15 per cent petrol added)
EGR	Exhaust Gas Recirculation
EPAQS	Expert Panel on Air Quality Standards
EPSRC	Engineering and Physical Sciences Research Council
ETBE	Ethyl Tertiary Butyl Ether
ETSU	Energy Technology Support Unit
EU	European Union
EV	Electric Vehicle
EVA	Electric Vehicle Association
HC	Hydrocarbons
IMI	Innovative Manufacturing Initiative
IPCC	Intergovernmental Panel on Climate Change
kW	KiloWatt (10 ³ W)
kJ	KiloJoule (10 ³ J)
LEV	Low Emission Vehicle
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LPGA	Liquid Petroleum Gas Association
M100	Pure methanol (M85 with 15 per cent petrol added)
MIRA	Motor Industry Research Association
MJ	MegaJoule (10 ⁶ J)
MTBE	Methyl Tertiary Butyl Ether
NERC	Natural Environment Research Council
NGV	Natural Gas Vehicle
NGVA	Natural Gas Vehicle Association
NiCd	Nickel-Cadmium (battery type)
NOx	Nitrogen oxides
O ₃	Ozone
OECD	Organisation for Economic Cooperation and Development
PAFC	Phosphoric Acid Fuel Cell
PAH	Poly-Aromatic Hydrocarbon
PEMFC	Proton Exchange Membrane Fuel Cell
PM	Particulate matter
PM10	Particulate matter of 10 microns diameter or less
PM2.5	Particulate matter of 2.5 microns diameter or less
PNGV	Partnership for a New Generation of Vehicles (in the USA)
POST	Parliamentary Office of Science and Technology
ppm	parts per million
QUARG	Quality of Urban Air Review Group
RCEP	Royal Commission on Environmental Pollution
RME	Rape methyl ester (biodiesel)

SMMT	Society of Motor Manufacturers and Traders	
SO ₂	Sulphur dioxide	
SOFC	Solid Oxide Fuel Cell	
SPFC	Solid Polymer Fuel Cell	
UKPIA	United Kingdom Petroleum Industry Association	
ULEV	Ultra Low Emission Vehicle	
VAT	Value Added Tax	
VED	Vehicle Excise Duty	
VOCs	Volatile Organic Compounds	
WHO	World Health Organisation	
		AA
		AA1
		ACEA
		AECC
		ASTI
		BABFO
		CAFE
		CDTI
		CNG
		CO
		CO ₂
		COMBAT
		CST
		DME
		DIRP
		E10
		E100
		EGR
		EPACT
		EPSC
		ETBE
		ETSU
		EU
		EV
		EVA
		HC
		IMI
		IPCC
		kW (100)
		kJ (100)
		LEV
		LPG
		LPG
		LPGA
		M100
		MIRA
		MI
		MTBE
		NERC
		NGV
		NGVA
		NICI
		NOx
		O ₃
		OECD
		PAFC
		PAH
		PEMFC
		PM
		PM10
		PM2.5
		PNQV
		POST
		ppm
		QUARD
		RCEP
		RME

APPENDIX 3

List of Witnesses

Those marked * gave oral evidence.

- Professor Paul Acarnley, University of Newcastle-upon-Tyne
 Dr Paul Adcock
 Professor Ross Anderson, St George's Hospital Medical School
 ARCO Chemical Europe
 Association of County Councils
 Association of London Government
 * Automobile Association
 Automobile Emissions Control by Catalyst (AECC)
 Norman E Bagshaw Esq
 * British Association for Bio Fuels and Oils
 * British Gas plc
 Professor P Bruce, St Andrew's University
 London Borough of Camden
 * Professor Chris Cernes
 Chemoxy International plc
 Clean Diesel Technologies Inc
 Confederation of Passenger Transport
 Robert Copcutt PhD
 Dr Steven Cousins
 Dr P T Davies
 * Department of the Environment
 * Department of Trade and Industry
 * Department of Transport
 * Electric Vehicle Association
 Electricity Association
 Engineering and Physical Sciences Research Council
 English Nature
 European Advanced Lead-Acid Battery Consortium
 European Biodiesel Board
 * European Commission
 Dr Margaret Farago
 * Ford Motor Company Ltd
 Freight Transport Association
 GKN plc
 Edward Gobina Esq, University of Salford
 Geoffrey Harding and Associates
 David Hart Esq
 Roy C Hatch Esq
 HM Treasury
 Dr Günter Hörmandinger
 ICI Group
 Institute for European Environmental Policy
 Institute of Road Transport Engineers
 Institute of Physics
 Institution of Chemical Engineers
 Institution of Civil Engineers
 Institution of Electrical Engineers
 Institution of Mechanical Engineers
 JCB Research
 * Johnson Matthey plc
 Professor Martin Lawson
 Liquid Petroleum Gas Association
 Professor Nigel Lucas
 Lucas Industries plc
 Dr Thomas Markvart

- Dr Philip Mitchell
- * Mobil Oil
 - Motor Industry Local Authority Network
 - * Motor Industry Research Association
 - National Farmers' Union
 - National Power
 - Natural Environment Research Council
 - * Natural Gas Vehicle Association
 - Nissan European Technology Centre
 - Policy Studies Institute
 - Powergen
 - W H S Rampden Esq
 - * Ricardo Consulting Engineers Ltd
 - Alan Ridge Esq
 - Rover Group
 - Royal Academy of Engineering
 - Royal Mail
 - S H Salter Esq
 - * Professor Anthony Seaton
 - * Society of Motor Manufacturers and Traders
 - Professor B C H Steele
 - Swedish Transportation and Communications Research Board
 - * Mr Ian Taylor MP, Minister for Science and Technology
 - Professor Iain Thornton
 - Transport Research Laboratory
 - United Kingdom Petroleum Industry Association Ltd
 - Roger Vaughan Esq
 - Volvo Truck and Bus Ltd
 - Wavedriver
 - * Keith Williams Esq

The Committee also acknowledges the assistance of:

ADA
 ADAC
 BMW
 Canadian High Commission, London
 Daimler-Benz
 Federal Government of Germany
 Financial Times Automotive Environment Analyst Newsletter
 Foreign and Commonwealth Office
 F J Gardner Esq
 MAN
 Ministry of International Trade and Industry, Japan
 Society of Chemistry and Industry
 Varsity Perkins
 Vauxhall Motors Ltd

APPENDIX 4

*Visit to Ford Motor Company Ltd's
Research and Engineering Centre, Dunton, Essex*

Tuesday 7 May 1996

Present:

L. Dixon-Smith (Chairman)
L. Lewis of Newnham
L. Perry of Walton
E. Selborne

The Sub-Committee travelled to Ford Motor Company Ltd's Research and Engineering Centre at Dunton in Essex.

The Sub-Committee heard presentations on the following subjects:

1. Background to "Towards Zero Emissions"
2. Gasoline engine technology
3. Diesel engine technology
4. Alternative fuels
5. After-treatment fuels
6. Calibration
7. Certification/Conformity
8. Alternative propulsion systems
9. Emerging market scenarios
10. Education—University curricula etc

Ford agreed to answer in writing members' questions on the proportion of energy which went into the construction of a vehicle and the proportion of energy which was consumed while the vehicle was in use, and on the recyclability of vehicles (p 89).

The Sub-Committee witnessed demonstrations of a catalyst light-up system which enabled the catalyst to reach optimum temperature in seconds, an Ecostar electric van, and three vehicles powered by compressed natural gas. The Sub-Committee then toured the engine testing facility.

APPENDIX 5

Visit to natural gas refuelling station and Johnson Matthey Technology Centre

Thursday 4 July 1996

Present:

L. Dixon-Smith (Chairman)
L. Porter of Luddenham
L. Redesdale
L. Walton of Detchant¹

Natural Gas Vehicle Association, Slough Refuelling Station*Introduction*

1. The Sub-Committee visited a natural gas vehicle refuelling station in Slough, operated by the Natural Gas Vehicle Association. The refuelling technology, storage systems and operation of the refuelling station were demonstrated. A wide variety of natural gas vehicles was also on display and demonstrated. These included vehicles operated by Slough Borough Council which has three compressed natural gas (CNG) vehicles out of a fleet of 170. The presentations and demonstrations were made by Mr Fred Parker, Mr Tom Gorman, Mr Paul Wray, Mr Richard Barski and Mr David Burnicle.

Filling station

2. The filling station was described as a prototype for what might be added as a module to existing petrol stations. The station had the capacity to refuel approximately 300 cars or 20 larger vehicles (eg buses, large trucks etc) per day. Fuel is supplied to the filling station via the gas mains and then stored on site in an array of small compressed gas cylinders. Gas is dispensed to the customer at pressure through what appeared to be a standard fuel pump with added safety and anti pollution devices. The filler nozzle is locked to the vehicle during refuelling to maintain a pressure seal and the system has a return valve to capture any gas remaining in the nozzle when disconnected. Wastage, for example through leaks and refuelling spills, was said to be zero because the in-built safety systems designed to protect public health also protected the environment. The gas distribution system overall was said to have a leakage of less than one per cent.

3. The gas is sold in kilograms (because of United Kingdom law) and is weighed using a coriolis meter as it is dispensed. It was suggested that selling fuel in this way might confuse many potential customers, and in particular the general public, who were used to buying fuel in litres or gallons. Gas suppliers thus wished to be able to sell the fuel in terms of a "petrol equivalent", but a change in the law was required for them to do this.

4. The on-site storage array consisted of approximately 50 connected gas cylinders, placed above ground for reasons of safety and ease of access. The system incorporated comprehensive pressure release and fire safety systems. The cylinders are mass produced, and thus relatively cheap, and individual cylinders could be replaced easily if any problems were identified. This was contrasted to the standard fuel storage system at petrol stations which were renowned for leaks, contaminated the local ground, and were very difficult and costly to replace.

5. An electric compressor was used on site to fill the storage array. Gas in the storage array was at 250 bar, to provide a positive pressure to the vehicle storage tanks which operated at up to 200 bar. At this pressure difference refuelling times were similar to using petrol. Faster refuelling could be achieved using higher pressures (the standard storage array pressure in the USA was 350 bar). Such "fast fill" systems where the gas is stored at greater than 200 bar would be required for street-side refuelling, but the greater the storage pressure, the more energy was wasted in

¹ Lord Walton of Detchant did not attend the visit to the Johnson Matthey Technology Centre.

compressing the gas. Systems which filled the vehicle tank to 200 bar from the mains over a longer period of time, without the need for on-site storage or compression, were the most energy efficient. Eventually these "slow fill" systems might become widely available for overnight home refuelling, and they were already in use by a bus company in Southampton which was running a fleet of CNG vehicles.

6. The cost of a full-sized natural gas refuelling station with equivalent capacity to a standard petrol station was estimated to be around £3/4 million. This was about three times the price of a traditional filling station. In the long-term, however, costs were much lower because there was no need for distribution tankers or complex refineries etc.

Vehicle demonstrations

7. The vehicles on display included cars, small vans and a minibus, a 45 seat bus, a refuse vehicle and the tractor unit for a 32 tonne truck. The vehicles covered three generations of developments in the United Kingdom. The first two generations were bi-fuel vehicles also capable of running on petrol, and they were fitted with catalysts optimised for petrol use. The first generation used normally aspirated engines drawing gas into the engine at atmospheric pressure (approximately 1 bar), the pressure from the storage tank having been reduced through a series of pressure drops. The second generation used a fuel injection system, with gas forced into the engine under pressure. The third generation vehicles were mono-fuel, fuel injected, operated at an increased compression ratio and had a catalyst which was "semi-optimised" for oxidising methane. Future generations of vehicle were expected to have multi-point fuel injection, complex engine management systems and palladium-based catalysts that were fully optimised for methane oxidation.

8. The 32 tonne ERF truck (one of the largest CNG road vehicles available) had a 12 litre Perkins engine dedicated to natural gas. Fuel storage was in large aluminium gas cylinders clad in fibreglass. The range of the vehicle was said to be 360 miles on full tanks. Currently the vehicle was used as part of the delivery fleet for a major high street retailer.

9. The technical aspects of natural gas vehicles were said to be in a high state of development with no fundamental problems remaining. Engine and catalyst technical developments were continuing, problems with variable fuel quality could be overcome by using on-board sensors linked to the engine management systems, and adsorbed gas storage systems were due on the market in the next five years. This latter development was expected to make CNG vehicles increasingly attractive to private buyers. The main obstacle to the up-take of CNG as a vehicle fuel was said to be the tax regime: major tax concessions over the next 10 years were thought to be a priority.

Johnson Matthey Technology Centre, Sonning

Introduction

10. Johnson Matthey is involved in research with precious metals and their application to fuel cells and catalyst technology. Presentations on research into these applications were made by Dr J C Frost, Dr G McGuire, Mr R J Evans, and Dr P N Hawker. Mr John Sheldrick, the Executive Director of Johnson Matthey, and Mr Ian Stephenson, the Environment, Health and Safety Director, were also present.

Fuel Cells

11. Individual fuel cells described in the presentation consisted of two solid graphite plates approximately 0.5 cm thick covered in a complex pattern of grooves. A carbon backing paper with a coating of carbon-supported catalyst was laid on the grooved surface of each plate. The two plates and catalyst layers were arranged in a sandwich separated by a proton exchange membrane. Oxygen was supplied to the grooves on one plate, and hydrogen to the other plate, through inlet valves.

12. The cells operated at 0.7 volts with a current density of around 0.8 amps per cm², and about 50 per cent thermal efficiency. Cells were connected together in series as a fuel cell stack to produce 300 volts or more. A major limitation on individual cell performance was voltage loss through the activation energy required to dissociate oxygen at the cathode. This was a problem that had yet to be clearly defined and required further basic research. At greater current densities the cell performance also declined rapidly as the amount of heat produced increased and the mass transport of reactants and products became a problem—the more work that was required, the more

hydrogen and oxygen that had to be supplied and the more water (the reaction product) that had to be removed. One of Johnson Matthey's major technical targets was to achieve 1.4 amps per per cm^2 at 0.7 volts.

13. Initially the cost of the catalysts was the main stumbling block for fuel cells, but now costs were said to be very close to targets thought suitable for use in cars. The costs of electronics, fabrication and the membrane had also reduced since the start of the Johnson Matthey programme in 1993. The plates themselves were now one of the most expensive (and heaviest) components because they had to withstand a very acidic environment and not poison the catalyst action. It was likely that plates in the future could be made of cheap (and light) metal coated with carbon, and that the cell could be manufactured as one unit through a thick-layer deposition process.

14. Most hydrogen for fuel cells is produced from natural gas. Johnson Matthey is conducting research into a fuel cell "reformat system" to generate hydrogen on-board a vehicle as it is required, thus eliminating the need for hydrogen storage. A hydrocarbon feedstock (eg ethanol or methanol derived from natural gas) is fed into a fuel processor (the "hot spot reactor") with water and air, and then the products are cleaned up to produce a mixture of hydrogen (54 per cent), carbon dioxide (24 per cent), nitrogen (21 per cent), and minor amounts of water and carbon monoxide. The overall efficiency of the system from natural gas, through methanol, the reforming process and then use in the fuel cell was said to be around 25 per cent. For direct combustion of the natural gas in a CNG car the system efficiency was said to be around 12.5 per cent.

15. The technology of fuel cells and associated systems was now well advanced, and the main problem now was how to take working cells through to successful commercialisation. The main barriers were thought to be: materials costs, improving the fuel processing systems for producing hydrogen on-board (or at a depot), the lack of a hydrogen refuelling infrastructure, excessive regulations on safety, and resistance to change away from the use of tried and tested internal combustion engines.

Catalysts and particle traps

16. Research was being conducted into a continuously regenerating trap (CRT) for diesel vehicles which was highly effective at reducing emissions of particulates as small as 40 nm in diameter. The greatest number of particles emitted in diesel exhaust were said to be less than 100 nm in diameter. These, predominantly carbon, particles could be trapped in a filter, and the trap was "regenerated" (unblocked) periodically by burning the particles to produce carbon dioxide. However, the reaction was inefficient or did not occur at less than 600°C and diesel exhaust rarely exceeded 450°C. The solution was to use nitrogen oxides, which were already present in the exhaust, to destroy the particles in a reaction that occurred at 240°C to produce carbon monoxide and nitric oxide (NO).

17. In lean-burn direct-injection petrol engines there is a higher ratio of air to fuel than in a conventional engine; the problem is how to catalyse the NO_x by reduction in an oxygen-rich exhaust environment. Johnson Matthey was working on a rhodium catalyst and a system that stored exhaust NO_x as a nitrate (eg barium nitrate)—the NO_x could then be released from this store and reduced periodically by running the engine rich (low air:fuel ratio) for a few milliseconds. The system depended on using a fuel with a very low sulphur content to prevent sulphate particles being produced.

18. Low sulphur fuel was also critical to the operation of the diesel CRTs and catalysts, not least because at high sulphur content the catalysts were poisoned and stopped working. The EU standard of 500 ppm sulphur to be introduced later in 1996 was described as pointless. If the CRT system were operated with such fuel the sulphur dioxide produced by combustion would be oxidised to sulphur trioxide which would then react to form sulphate particles in the atmosphere, so the process would be self defeating. It was known that the very low sulphur content of some clean Scandinavian fuels (less than 10 ppm sulphur) was suitable, but this was expensive to produce and it was suggested that a standard of 50 ppm sulphur in diesel would be reasonable. Similarly, 50 ppm sulphur in petrol would also mean that the lean-burn catalyst technology could be made to work effectively.

19. In making a call for both diesel and petrol with around 50 ppm sulphur it was said that these fuels would also help to clean-up emissions from existing vehicles. An early introduction of such fuel standards was thought to be essential because the fuel needed to be widely available before cars equipped with CRTs or lean-burn engines were put on the market.

APPENDIX 6

*Visit to Germany***Tuesday 9 July – Friday 12 July 1996***Present:*

- L. Dixon-Smith (Chairman)
- L. Perry of Walton
- L. Redesdale
- L. Soulsby of Swaffham Prior

The Sub-Committee travelled to Germany on Tuesday 9 July, attending a dinner at the Minister's Residence in Bonn that evening. On Wednesday 10 July the Sub-Committee held discussions with the Federal Ministries of Economics (BMWi), Environment (BMU), Education, Research and Technology (BMBF) and Transport (BMV). Over lunch a short presentation was given by a representative of ADAC (the German equivalent of the AA). On Wednesday evening the Sub-Committee travelled to Munich, and on Thursday it visited the heavy vehicle company MAN and BMW. On Thursday evening the Sub-Committee went on to Stuttgart; on Friday it visited Daimler-Benz and the ADA, a research centre into catalyser and clean-up technology established by the German motor manufacturers.

Tuesday 9 July

The dinner at the Minister's Residence was hosted by Mr Robert Barnett, a Counsellor on Science, Technology and the Environment and Dr David Bacon, First Secretary on the Environment at the British Embassy in Bonn. Also present were Frau Monika Ganseforth, a member of the Bundestag since 1987 who speaks on transport issues for the SPD; Herr MinR Ulrich Näke from the Federal Environment Ministry; Herr Prof Rolf Theenhaus, a member of the board of Jülich, one of Germany's major scientific research centres; Frau Dr Maren Ernst-Vogel, the head of the Bonn office of the German Mineral Oil Industry Association; Herr Dr Joachim Herth and Dr Klaus-Peter Schindler, both from Volkswagen; Herr Stephan Zieger, from one of Germany's trade associations for fuel trade and refuelling stations and Herr Prof Günter Zimmermeyer, Environmental spokesman of the VDA (the German society of motor manufacturers).

Frau Ganseforth (SPD transport spokeswoman) argued that it was important to consider other issues in addition to vehicle technology, such as the need to travel less and the need to encourage people to switch between modes of transport. Herr Zimmermeyer (VDA) agreed that new vehicle technology could not solve all of road transport's problems; politicians had to ensure that traffic was kept moving as the most fuel efficient vehicle was very inefficient if it was stuck in a traffic jam. He also stated that it would be easier to reduce carbon dioxide emissions from other sectors (eg. domestic heating) than from road vehicles. Herr Zimmermeyer went on to outline the voluntary agreement by the German automotive manufacturers to make a 25 per cent reduction in the fuel consumption of the average new car in 2005 compared to the average new car in 1990.

Herr Theenhaus (Jülich research centre) argued that fuel cells would come into use long before a hydrogen production and distribution network was a realistic possibility. Therefore for the next one to two decades the fuel used would have to be methanol or CNG reformed to hydrogen on board the vehicle.

Herr Zieger (refuelling stations trade association) discussed the Federal Government initiative to part-finance the construction of new CNG refuelling stations. He stated that there was little incentive for building public refuelling stations as there were not enough privately owned CNG vehicles to make it worthwhile. Most of the CNG vehicles in use were part of a fleet which refuelled at a central depot. In itself the cost of building a new station—at around DM 250,000 or £100,000—was not prohibitively expensive.

Wednesday 10 July

The Sub-Committee visited four German Federal Government Ministries:

(1) *Economics (BMW)*

Present were Herr Dr Heitzer (Deputy Director General Environment and Industry), Herr MinR Dr Muttelsee (basic issues including air quality and vehicles), Herr Heinze (involved with the Auto-Oil programme) and Frau Bierbrauer.

(2) *Environment (BMU)*

Present were Herr MinDirig Dr Westheide (Deputy Director General, Air Quality, Noise, Plant Safety and Transport) and Herr Dr MinR Knobloch (Fuel, new motive and transport systems and air transport).

(3) *Education, Employment and Research (BMBF)*

Present were Herr Dr Döllinger (Deputy Director General, Aerospace, Transport and Marine Technology) and Herr Schröder.

(4) *Transport (BMV)*

Present were Parliamentary State Secretary Johannes Nitsch, Herr MinR Ulrich Näke (Basic transport issues), Herr Baudirektor Helmut Krämer (Environment) and Frau Bauoberrätin Monika Bernitt (Vehicle technology and environment).

The economic climate

The BMW said that there had been a short boom in the wake of German re-unification in 1990, but that this boom had been followed by a recession. The economy had now recovered to a degree, but there was still concern that over-stringent environmental regulations would deter investment and cost jobs.

Transport policy

Herr Westheide summarised the thrust of German transport policy from the BMU's point of view. The main aims were to avoid unnecessary traffic, which required efficient use of land, to switch traffic to less polluting modes (eg. from air to train, from car to bicycle), and to protect local air quality. To achieve this last goal the regional governments (Länder) had been given the power to ban or restrict traffic if certain air quality values were exceeded. Traffic could be restricted or banned if ozone concentrations exceeded 240 microgrammes per m³ in one hour. New powers would come into force in 1998 to ban or restrict traffic if benzene concentrations exceeded 10 microgrammes per m³, and soot particle concentrations exceeded 8 microgrammes per m³ (benzene is used as an indicator of petrol engine derived pollution, and soot as an indicator of diesel engine pollution). The BMU hoped that new vehicle technology would remove the need for these powers to be used.

Carbon dioxide

The Federal Government has stated (for example at the Rio Summit in 1992) that it aims to reduce overall carbon dioxide emissions in Germany by 25 per cent by 2005, with 1990 as the base year. The necessary measures are currently under discussion. Officials stated that the Government would prefer not to introduce legislation, relying instead on voluntary agreements of which the automotive industry agreement was an early example. Herr Muttelsee (BMW) added that there was, however, no need for exactly proportional cuts; smaller reductions in the transport sector might be balanced by larger reductions in other sectors.

The BMW was particularly wary of prescribing fuel consumption limits for vehicles, pointing out that this would inevitably hit companies which produced larger cars (eg. BMW, Daimler-Benz) harder than those which produced smaller cars (eg. Italian companies such as Fiat). The Ministry was therefore opposed to the proposal at the recent meeting of the European Union Environment

Council that there should be a limit of 120 grammes per kilometre for carbon dioxide emissions from passenger cars by 2005 (equivalent to 5 litres per 100 km for petrol vehicles, 4.5 litres per 100 km for diesels). Insisting that the date was unfeasible, the UK and Germany inserted an opt-out clause stating that should the target prove impossible by 2005, 2010 could be adopted as an alternative date.

Motor vehicle taxation

The current annual tax on motor vehicles is graduated according to the size of a vehicle's engine (and hence related to fuel consumption per mile). This will shortly be modified so that the tax reflects both fuel efficiency and noxious emissions. It is planned that in the longer term the tax will be abolished altogether and the money lost will be recouped through higher fuel duty (the proposed date for this alteration in 2003). One of the reasons that this has not been done already is that fuel duty goes to the Federal Government, while the annual vehicle tax goes to the Länder. Naturally, many of the Länder oppose any reduction in their tax raising powers.

Fuel

All the government officials welcomed the approach embodied by the Auto-Oil programme but deplored some of the resulting proposals. Most of their criticism was concentrated on the limit values for fuel standards. The BMU was fiercely critical of the "lax" limits for benzene. Herr Westheide stated that the German average benzene content in petrol was already 2 per cent (the limit proposed for 2000 under the Auto-Oil programme), and that this caused concentrations to exceed regularly their recommended air quality limits.

The limits for sulphur in both petrol and diesel were also fiercely attacked as being too high. The Commission proposes that the limit in petrol should be 200 parts per million (ppm), and in diesel 350 ppm. Officials from the BMU argued that a reduction catalyst to deal with NOx emissions from diesel vehicles would be available by 2000, but that as it was poisoned by sulphur it would be useless without very low sulphur fuel being widely available. The maximum limit for diesel should be 50 ppm by 2000; the need for low sulphur petrol was less urgent and could wait until 2005. They claimed that this would only cost the motorist 2 or 3 pfennigs a litre extra. They also attacked the Commission proposal for a low sulphur "City fuel", which could be prescribed for cities with a pollution problem, as it would complicate the working of the European fuel market. There was a need to combine environmental objectives with the objective of the single market.

The Sub-Committee learned that heavy metal additives must be licensed by the German Environmental Protection Agency and that the testing process can take some years. The cerium additive produced by Rhone-Poulenc has not yet been approved for use.

The BMBF did not consider that biodiesel could make a substantial contribution to reducing pollution from road transport, noting that its impact would probably be greater on the agricultural sector. They stated that there was no research into the genetic engineering of plants to increase yields, largely due to public antagonism to any form of genetic engineering.

Diesel

The BMU did not consider that diesel vehicles should be encouraged at the expense of petrol vehicles, as the air pollution disbenefits cancelled out the gain in fuel economy. The fuel duty on mineral diesel is lower in Germany than the petrol duty, but this is chiefly because Germany has to follow the countries which surround it, or many drivers, especially those of HGVs, would simply fill up over the border. The government attempts to recover some of this revenue through higher road tax and annual taxes on larger vehicles (which are almost invariably diesels).

Older vehicles

Herr Muttelsee (BMW) stated that catalytic converters had been introduced on a non-compulsory basis in 1985, and had been compulsory on new cars since 1992. As a result 60 per cent of German vehicles were already fitted with catalytic converters. That proportion was expected to rise to 75 per cent by 2000. The idea that vehicles not fitted with converters should be banned outright had been given up as not cost-effective.

Compressed Natural Gas Vehicles

The BMU conceded that the provision of a refuelling infrastructure was the weak point in the promotion of the use of CNG powered vehicles. Nevertheless, CNG offered great emissions advantages over both petrol and diesel (CNG vehicles can meet or better the proposed European Stage III emissions limits), and should therefore be encouraged. The Federal Government had calculated that the lowering of the CNG fuel duty in the last budget to near the EU minimum should, over the lifetime of the vehicle, cover the extra cost of buying a CNG vehicle. The government is also offering a subsidy to cover 50 per cent of the extra cost of buying a CNG vehicle as opposed to a diesel equivalent, and a cheap loan to cover the rest of the cost. The next step will be a planned demonstration project in one town, making a public refuelling infrastructure available. The government now considers that it has carried out its part of the bargain, and is pressurising the gas industry to supply the infrastructure. Gas supply is at present a monopoly in Germany; the BMU was very keen on deregulation as it might stimulate some competition. One advantage that CNG enjoys is that the public are familiar with natural gas, albeit in a different context. It was emphasised by several officials that any new technology must be taken up by the public to be successful.

In the long term many of the officials saw CNG as a potential route to a hydrogen supply network; in the intermediate term it might also be possible to run vehicles on a mixture of CNG and hydrogen, mixed either in the distribution network or on the vehicle itself.

Car of Tomorrow

The BMBF argued that the Car of Tomorrow programme was too limited, and that it ought to encompass more than the environment. In the USA, the Partnership for a New Generation of Vehicles was also focused on the promotion of the competitiveness of American industry; it was argued that this was a more sensible model to follow.

Battery vehicles

The BMBF outlined a large scale testing programme for battery powered vehicles which began in 1992, in which 60 vehicles and three different batteries were involved, on the German island of Rugen. The first was the nickel chloride-sodium (zebra) type, which operates at 300°C and offers a maximum possible range of 200–220 kilometres. The sodium-sulphur battery initially performed the most impressively, but due to the high operating temperature some of the batteries caught fire and those vehicles powered by sodium-sulphur batteries had to be withdrawn from the test. [Note—Ford's Ecostar van is powered by a sodium-sulphur battery. The Ford engineers denied any safety problems with their version, but conceded that the energy density needed to make it a viable commercial proposition was still far off]. The third battery tested was the nickel-cadmium battery, which had the greatest potential for cost-reduction if mass-produced.

It was stated that at present there were only 4500 battery vehicles in use in Germany, but that the government hoped to see a substantial increase in this figure in 5 to 10 years time. It was added that the Japanese seemed to be in the lead with the development of lithium batteries, which could be used in the new microcars coming on to the market in Asia. Although batteries were not yet commercially viable, increasingly strict emissions limits on the internal combustion engine might help to make them so.

Fuel cells

The energy division of the BMBF is supporting research into fuel cells for transport purposes, although some doubt was expressed by the BMU that their cost would ever fall to approximately that of an internal combustion engine.

Hydrogen

The BMU discussed the prospects for the production of cheap hydrogen from a renewable source. It was argued that there was a strong case for European-wide research programmes into the long-term prospects for hydrogen generation. Germany itself is pursuing research in collaboration with Saudi Arabia into the production of hydrogen by the electrolysis of water, powered by electricity derived from solar cells. Germany itself is not as sunny as Saudi Arabia, and would

probably have to continue importing a large amount of its energy needs even if there were a significant switch from fossil fuels to solar energy. The Sub-Committee was informed at the BMV that a workshop was planned to determine whether hydrogen or methanol should be preferred as the fuel for fuel cells.

Research

It was stated by the BMBF that the federal research budget was DM 30 million. Most of the money was directed towards industry, though a small proportion of the research was then sub-contracted out to universities. It was not thought feasible to increase greatly the amount of money going to universities as they did not have the equipment or the specialist knowledge of the larger companies.

Noise

Herr Knobloch (BMU) identified noise as a major concern of the government. He stated that some studies indicated that the stress caused by noise could in the long term be a contributory factor in causing heart attacks. The Sub-Committee was informed by both the BMU and Herr Zimmermeyer (at the dinner on Tuesday 9 July) that the noise output of individual vehicles, and especially heavy vehicles, was now vastly reduced in comparison to the 1970s.

ADAC presentation

Over lunch on Wednesday a short presentation was given by Herr Linde of the ADAC (the German equivalent of the AA). In the course of the presentation he stated that the proper role of government was to lay down regulations well in advance so that companies knew what they had to do; invest in research and development directly; and also prime the public to accept new technology when it came on to the market. ADAC agreed with the UK's AA that while there might be scope for altering the balance of motoring taxation from one tax to another, the overall level of taxation on motor vehicles was about right.

Thursday 11 July

MAN

MAN is a company which specialises in producing trucks, buses, and other heavy road vehicles. Other divisions of the company also produce massive diesel engines, for example for sea going ships. MAN were represented by Herr Dr Schubert, board member responsible for technology, Herr Hahn (Head of Division, Technical Services), Herr Dr Held (Head of pre-development, engines, at Nürnberg site) and Herr Drewitz, (Head of pre-development, Munich). Presentations and discussions were followed by a demonstration of MAN's most recent CNG powered bus.

The largest part of MAN's business is in the commercial vehicle sector, where they employ 26,000 people and have an annual turnover of around DM 7000 million. MAN informed the Sub-Committee that the average life of a truck is 10 years, during which time it would cover up to 1 million miles. Each model produced by MAN runs for around 15 years.

MAN scientists outlined the major problem which faced them; reducing emissions of noxious substances to meet anti-pollution directives from the European Commission meant increasing fuel consumption. They stated that achieving European Stage III emissions limits would bring with it a 10 per cent penalty in terms of fuel consumption, unless sulphur was removed from diesel fuel. The limits could be achieved by, for example, exhaust gas recirculation and particulate traps, but both of these methods carried a worse fuel penalty than a de-NO_x catalytic converter, which required low sulphur diesel of between 10–50 parts per million. MAN noted that this diesel would only be 6 to 8 per cent more expensive for the consumer than normal diesel, but conceded that even if such fuel were generally available tomorrow, the de-NO_x catalyst itself was not yet production ready. They hoped that the device would be on the market by 2000.

MAN argued that in addition to sulphur, the aromatics content of diesel should be reduced and the cetane index increased through the fuel standards directive arising from the Auto-Oil programme. They illustrated their case by quoting the result of a test showing the improvements in emissions which could be obtained from switching from fuel 1 to fuel 2 (in the same engine):

	Sulphur content	Aromatics content	Cetane index
Fuel One	0.05%	18%	51
Fuel Two	0.02%	8%	61

It was stated that hydrocarbon emissions were reduced by 13 per cent, NOx by 12 per cent, particulates by 15 per cent, while fuel consumption was reduced by 1 per cent. MAN also raised the question of the method used to test emissions, noting that this could be as important as the actual results gained from the test.

At most, 2 per cent of MAN's research work is government-funded. Very little of their work is contracted out to universities, as they have more advanced facilities in their own research centres. Despite uncertainty over government support for the project, MAN are going ahead with a fuel cell collaboration with Siemens (who are supplying the cell) and the gas company Linde.

MAN stated that they had been experimenting with the addition of urea to exhaust gases to assist with the reduction of NOx. Early test results indicate that this can reduce NOx by 61 per cent, though carbon monoxide emissions were slightly increased. It was thought that the need to fit a urea canister to the vehicle meant that the idea was only viable for larger diesel vehicles. There were other problems in that urea is toxic and smells.

MAN have developed trucks and buses which run on CNG. The company has sold around 90 CNG buses within Germany, and has also exported them to cities such as Adelaide and Bangkok. The purchase cost of one of their CNG buses is around 15 per cent more than the diesel equivalent. To invest any further in CNG, MAN stated that they would have to feel assured that there would be a fairly large market for their products, which did not seem to be the case at present. Even at 200 bar, the Sub-Committee was reminded that CNG has only one fifth of the calorific value of diesel.

BMW

BMW were represented by Herr Dr Teltschik, a member of the BMW board, Herr Dr Schindler, Herr Dr Klütting, Herr Dr Metz, Herr Haug, Herr von Kospoth, Herr Friedmann and Herr Geier.

Herr Teltschik gave a presentation on the company. He emphasised the need to give industry secure conditions in which to operate, and outlined BMW's long term strategy, which is to develop cars which can run on CNG or petrol, then vehicles which run on liquid natural gas (LNG), then in the long term to develop cars which can run on liquid hydrogen, either by burning it in a combustion engine or by using a fuel cell. BMW already have a bi-fuel CNG/petrol vehicle on the market; it is DM 7500 more expensive than its petrol equivalent. The Sub-Committee were given a demonstration of this vehicle, and a pre-production vehicle which used hydrogen in its internal combustion engine. BMW stressed the environmental advantages of natural gas over petrol and diesel; not only did it offer reduced noxious emissions, it also had a reduced overall greenhouse effect (even taking into account the global warming potential of methane).

Herr Schindler discussed the European emissions limits, offering the opinion that beyond Stage III it will be more effective to scrap older vehicles than it will be to drive new car emissions limits down even further.

BMW production concentrates on large cars; the fuel consumption of the average new BMW is one to two litres higher than that of the average new German car, which is in turn higher than the European Union average. This means that it will not be possible for BMW to achieve the proposed Environment Council target of 5 litres per 100 kilometres, whether they are given until 2005 or 2010 to do it. BMW did allow that fuel price is a very important determinant of fuel consumption. On current prices, they have calculated that it is cost-effective for a driver to pay DM 1500 to 2000 extra on the purchase cost of a vehicle if it will consume 1 litre of petrol per 100 kilometres less. However, fuel duty should not be raised any further as petrol and diesel road fuels are already taxed heavily for the amount of carbon dioxide they produce in comparison to, for example domestic heating.

Herr Haug stated that of the money that BMW receives from outside the company to carry out research, 38 per cent comes from the EU, 30 per cent from EUCAR projects (EUCAR is the

environmental and research wing of the European Motor Manufacturers' Association (ACEA)) and 19 per cent from the BMBF (German Ministry for Education, Employment and Research). He added that the American PNGV project was better conceived than the European Car of Tomorrow programme because it was at least as concerned with competitiveness (for example, harnessing former defence research bodies to carry out automotive-related research) as environmental aims.

Like MAN, BMW is carrying out fuel cells tests with Siemens. BMW produces no vans, and so they must be reasonably confident that the system will fit into one of their larger cars.

A slide was produced which showed that there are 40,000 battery powered vehicles on the road, and that 25,000 of them are located in the United Kingdom. The vast majority of this number is presumably made up of milk floats. BMW's own battery research is now focused on nickel chloride-sodium batteries, sodium-sulphur having been given up as too unreliable. BMW consider that 80 per cent charging of a battery in one hour will soon be possible. However, a note of caution was sounded when Herr Haug pointed out that petrol still has 100 times the energy density of the best battery. Furthermore, the power performance of a battery declines as it is used; this is not a problem with petrol.

Herr Geier stated that developing countries should attempt to introduce the most reliable and tested modern technology as quickly as possible. BMW had recently sent a trade delegation to China and suggested policies such as tax benefits for cleaner fuels and catalytic converters for all new cars.

Friday 12 July

Daimler-Benz

Daimler-Benz were represented by Herr Dr Kollmann, a member of the board of Daimler-Benz, Herr Breitschwerdt, Herr Kemmler, Herr Hoehl, Herr Noreikat, Herr Dr Krauss and Herr Dr Povel. After presentations and a discussion, the Sub-Committee was given a demonstration of the Necar II fuel cell vehicle and two battery powered vehicles.

Herr Breitschwerdt introduced the company. Daimler-Benz is a holding company for a range of other companies, of which Mercedes-Benz—the vehicle manufacturing arm of the operation—is by far the largest. Mercedes-Benz's sales in 1995 were DM 104 billion, and the research budget for 1996–98 is DM 10.9 billion.

The company has calculated that, with the present German electricity generating mix, battery vehicles have no clear carbon dioxide advantage over petrol or diesel powered vehicles. It was noted that 70 per cent of California's energy requirements are generated outside the state, and the energy which is produced within the state is largely from hydro or solar sources. Given this generating background, it therefore makes a great deal of sense for that particular state to introduce battery vehicles, but the same considerations would not apply everywhere.

Herr Krauss discussed Daimler-Benz's research work on the fuel cell, stating that today's fuel cells were at 1905–1910 levels of sophistication in comparison to the internal combustion engine. However, work was progressing very rapidly and the NECAR II van was far more advanced than the original NECAR. For example, the fuel cell now took up as much space as a conventional van engine. The fuel cell used was supplied originally by Ballard, but Daimler-Benz indicated that more of the technology they were now using came from their own scientists.

Abgaszentrum der Automobilindustrie (ADA)

The ADA is a co-operative research centre which was established by the major German motor manufacturers. It investigates advanced methods of exhaust gas treatment to reduce noxious emissions. The projects are focused on long term pre-competitive research, the results of which are made available to all the companies involved. ADA were represented by Herr Dr Sebbesse, the director of the ADA, Herr Dr Seifert, Herr Frech and Herr Degen.

Herr Sebbesse, gave a presentation on exhaust treatment. There were two fundamental options for converting pollutants to less harmful substances; catalysis or burning. Different solutions might have to be sought for the reduction of NOx in lean-burn petrol engines and NOx reduction in diesel

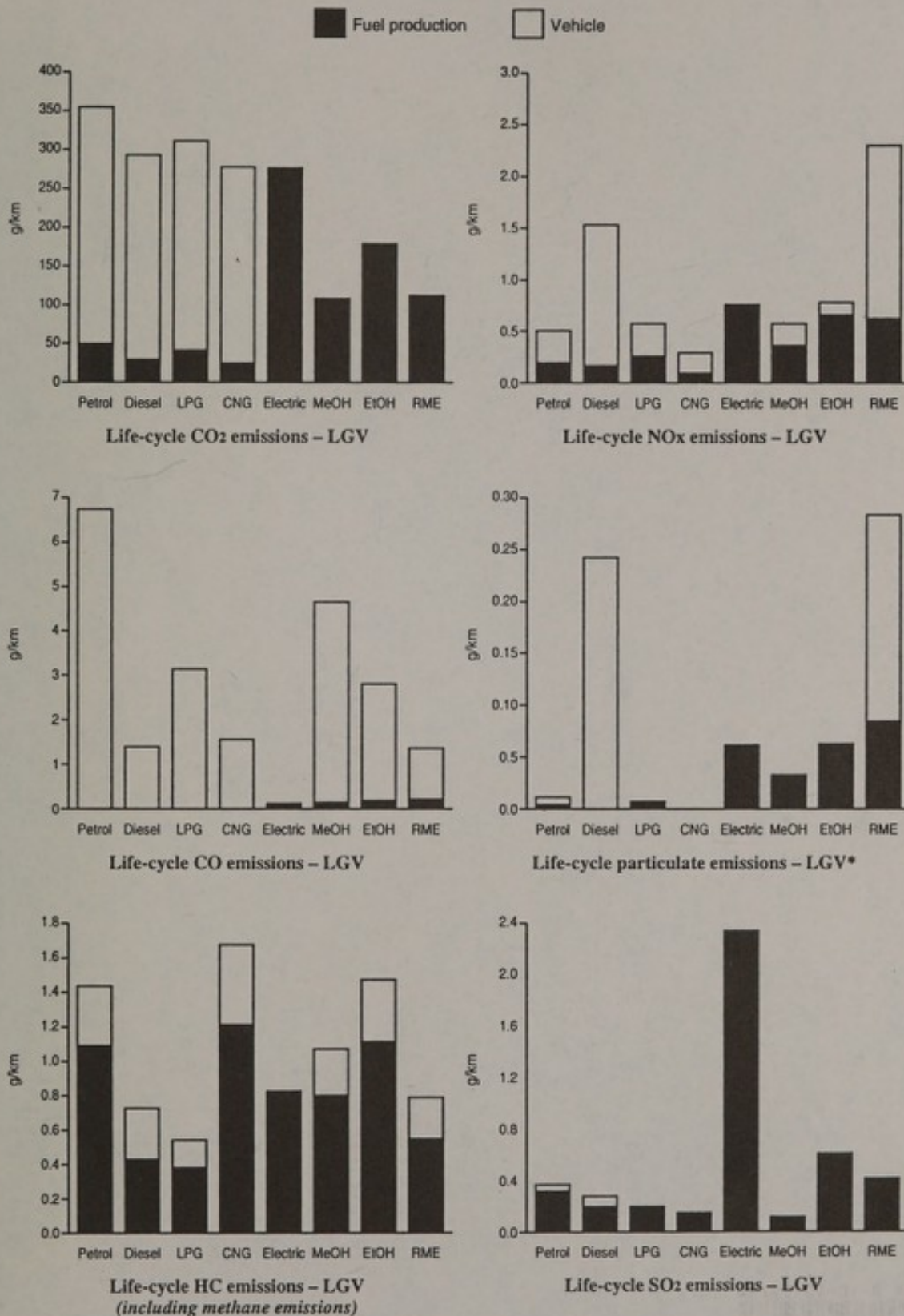
engines, partly because of the engines' different operating temperatures. Herr Sebbesse agreed that low sulphur fuels would help in the development of reliable catalysts to reduce NOx in an oxygen rich environment, but there were other more important problems to be solved first; at present the catalysts simply did not work very well, whatever fuel was used.

Herr Sebbesse raised the question; if NOx can not be removed from the exhausts of lean-burn petrol engines, is it worth accepting this as the price of improving fuel efficiency by around 10 per cent?

On the question of testing, Herr Sebbesse argued that there should be one commonly agreed test between all developed countries (at present there are different tests in the USA, in Japan and in the EU). This would provide a fairly realistic assessment of emissions in most areas as traffic conditions were converging all over the world.

APPENDIX 7

*ETSU Report on alternative fuels:
Overall life-cycle analysis of emissions from a Light Goods Vehicle*

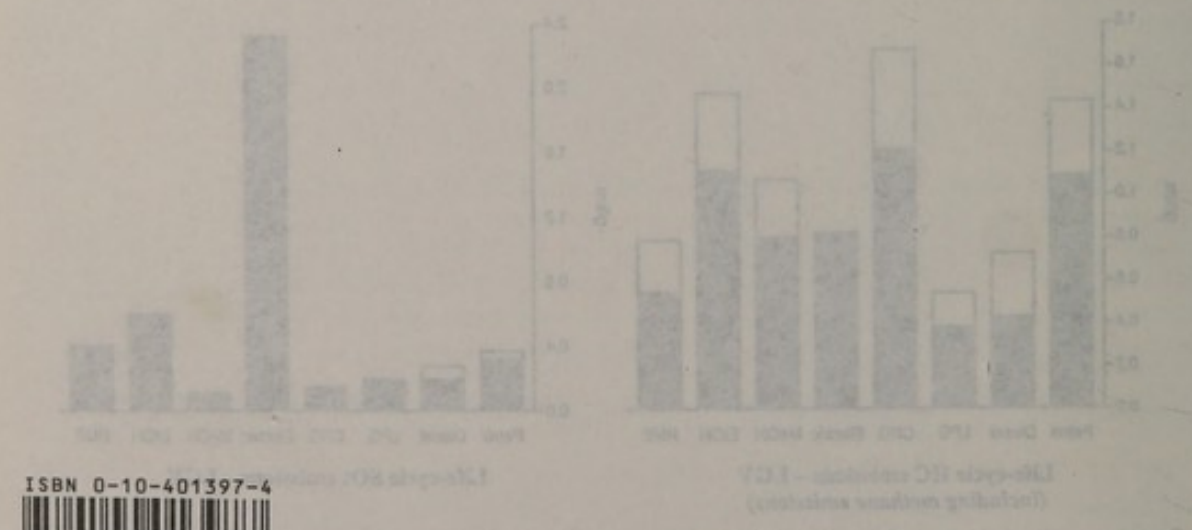
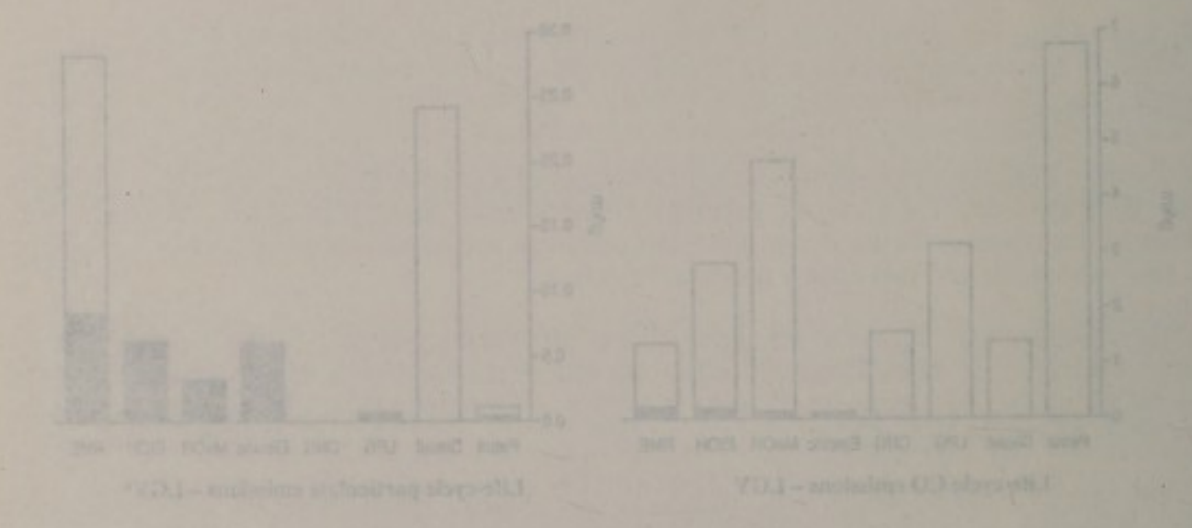
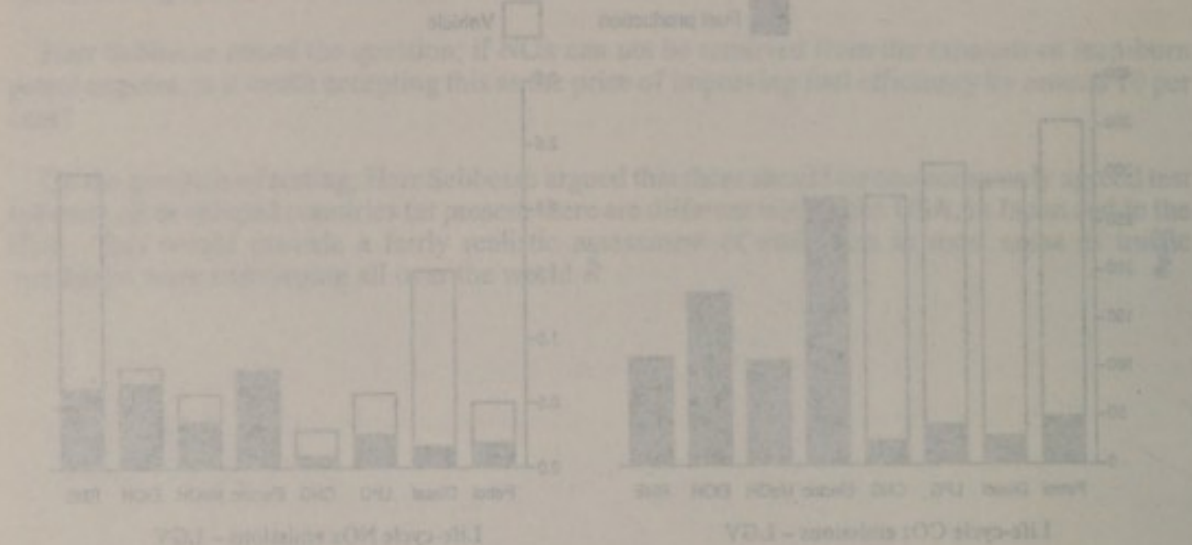


* Vehicle particulates for LPG, CNG, MeOH and EtOH are not shown as insufficient data available, but unlikely to be higher than for petrol.

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APPENDIX 7

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