The King Review
of low-carbon cars

Part I: the potential for CO_2 reduction

KING REVIEW

October 2007

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Foreword by Julia King

Sir Nicholas Stern's report, The Economics of Climate Change, published last year, highlighted both the need for action to reduce CO_2 emissions, and the consequences if we fail to act. Stabilisation of greenhouse gas levels in the atmosphere requires that annual CO_2 equivalent emissions be brought down most rapidly in developed nations – to 60-80 per cent below current levels by 2050. The costs of doing so are likely to be around 1 per cent of global GDP if we take strong action now. The costs of failing to act now are considerably higher – 5-20 per cent of global GDP.

The Chancellor announced in Budget 2007 that I would be undertaking a review with the support of Nick Stern, of the options for decarbonising road transport, especially cars. The Review reports to the Secretaries of State of four Departments – BERR, DfT, DEFRA and HM Treasury. This report summarises the findings of Part I of the Review, concerned with technology options. Part II will be published in 2008, and will make policy recommendations.

Mobility is a major driver of economic growth and societal development, so reducing CO_2 emissions from transport, especially our personal transport, is a particular challenge. Traffic is currently growing in the UK at the rate of about 1 per cent per year. If this were to continue at a similar rate up to 2050, the number of kilometres driven each year would almost double. In order to reduce emissions from cars to 20 per cent of 2000 levels we would actually need to achieve a 90 per cent reduction in per-kilometre emissions by 2050 to offset the effect of traffic growth. We have taken this challenge as the starting point for our Review.

While the challenge is large and urgent, the message in this report is a very positive one: it looks achievable – as far as anyone should risk predicting what will happen in 50 years time! Even more importantly, we, as consumers, can start to make a significant impact now, without sacrificing the comfort and convenience we enjoy from using our cars. In many cases the technology that cuts car emissions could also save drivers money.

Within ten years we could be driving equivalent cars to those we choose today, but emitting 30 per cent less CO_2 per kilometre. The technology is available. The urgent challenge for the short term is to develop a strong and rapidly growing market for low emissions cars. These signals will enable manufacturers to make the major investments required to deliver the technology in new 'green' models.

In the medium term, as we progress towards 2030, per-kilometre emissions reductions of some 50 per cent could be achieved through a combination of battery-electric hybrids – including plug-in versions – and biofuels, while more radical clean technologies continue to develop in niche applications. We must approach the development of biofuels with caution. They have an important role to play, but we must put appropriate international safeguards in place. The annual CO_2 emissions associated with deforestation amount to 18 per cent of global emissions – larger than the total global contribution from transport.

Long term, clean electric or hydrogen-powered vehicles are a probability. There are many exciting technical challenges to be overcome – e.g. batteries with an order of magnitude increase in energy density and new storage systems for hydrogen – and we have a strong research base to address these. However, while such vehicles will have zero CO_2 emissions on our streets, they will rely on clean electricity to provide truly low-carbon transport.

All of this looks achievable. Let me repeat the urgent challenge: it is to develop a strong and rapidly growing market for low emissions cars. And we all have a role to play.

Many people have contributed to this report in many ways. Individuals, groups and companies who contributed formally to our discussions and thinking are listed in the acknowledgements, and there have been many other valuable contacts at conferences and meetings. Particular thanks must go to Nick Stern for his advice and comments, and to Greg Archer of the Low Carbon Vehicle Partnership for the organisation of an excellent seminar series to address our key technology and behavioural questions. Dr Ian Ritchey of Rolls-Royce plc and Dr Alan Begg of SKF have also provided me with sage advice.

The real heroes of such a Review are of course the Review Team. Led by Chris Mullin from the Treasury and drawn from the four departments involved in this Review (BERR, DfT, DEFRA and HMT), they have worked effectively and with energy and enthusiasm to deliver this report. I am very much indebted to: Chris Mullin, Will Steggals, Greg Vaughan, Paul Kissack, James Hooson, Helen Roberts, Mel Rich, Adrian Murphy and Liz Hindson.

Julia King

October 2007

Executive summary

1. Road transport underpins our way of life. In all parts of the world, it takes food to markets, shops and homes; doctors to emergencies; individuals to work and back to their families. Since Henry Ford produced the Model T, the first mass-produced motor vehicle, a century ago, road transport has dramatically enhanced mobility, economic prosperity and quality of life for billions of people, as well as becoming a major industry in its own right. In the future, as the economies of the world continue to develop, there is no doubt that road transport use will expand further, bringing with it even greater benefits.

Growth, mobility and environmental responsibility

2. In 2000, cars and vans accounted for 7 per cent of global carbon dioxide (CO_2) emissions. This proportion is rising as economic growth brings the benefits of widespread car use to the world's emerging and developing economies. Under a business-as-usual scenario, global road transport emissions would be projected to double by 2050[1].

3. The global challenge is to support increases in road transport use, in a sustainable, environmentally-responsible way. Just as technology has helped achieve radical improvements in vehicle performance and safety since 1908, the industry is now addressing the greatest challenge yet: delivering environmental solutions.

The environmental challenge for road transport

Stern provides the overall environmental context

4. The Stern Review[2] on the Economics of Climate Change sets out the overall environmental challenge. As a result of the growing concentrations of greenhouse gas in the atmosphere, climate change threatens severe consequences including flooding, drought, population displacement, and ecosystem destruction across the globe. The benefits of strong, early action far outweigh the costs. To achieve greenhouse gas stabilisation at 550ppm[3], total emissions reductions (total across all sectors) of at least 25 per cent by 2050 will be needed, relative to 2000 levels. The 2007 G8 summit in Heiligendamm agreed an ambition of a 50 per cent reduction in global emissions by 2050 (relative to 1990). Stern asserts that the developed world, including the UK, needs to lead the way by achieving total emissions reductions of 60-80 per cent by 2050.

5. A challenge on this scale requires all sectors, including road transport, to make urgent and substantial progress in reducing CO_2 emissions. This is why, in Budget 2007, the Chancellor of the Exchequer set up the King Review to "examine the vehicle and fuel technologies that, over the next 25 years, could help to decarbonise road transport, particularly cars."

[1] http://www.hm-treasury.gov.uk/media/8/D/Transport_annex.pdf.
[2] *Stern review on the economics of climate change*, 2006.
[3] Parts per million, CO2 equivalent greenhouse gases in the world's environment.

Long term, an 80 per cent reduction in UK road transport emissions is feasible

6. In the long-term (possibly by 2050 in the developed world), almost complete decarbonisation of road transport is a possibility. If substantial progress can be made in solving electric vehicle technology challenges and, critically, the power-sector can be decarbonised and expanded to supply a large proportion of road transport demand, around a 90 per cent reduction per kilometre emissions would be achievable across the fleet. If the rate of road transport growth projected by Eddington[4] continues, and road use in the UK approximately doubles by 2050, this could deliver an 80 per cent reduction in total road transport CO_2 emissions, relative to 2000 levels.

7. As well as focusing now on the technologies that can achieve the long-term objective of decarbonising road transport, it is important to start reducing emissions in the short term, through development and implementation of improvements to established automotive technologies. As Stern highlights, emissions avoided now are more valuable than those saved later. This Review's analysis indicates that, by 2030, emissions per kilometre could be around 50 per cent below 2000 levels. This would be partly offset by the projected increase in distance travelled, implying an overall reduction in UK emissions from car use of approximately 30 per cent by 2030.

8. This is a major challenge: urgent and sizeable. This review does not set targets for the road transport sector. Instead it focuses on what can be achieved, through strong action now, towards the long-term decarbonisation of cars. Even in the short term, we can achieve significant reductions in CO_2 emissions through use of technologies that are already available, and by making smart choices, as individuals, about what, when and how to drive.

9. There is no single solution. To achieve this goal substantial progress is needed across the board:

- cleaner fuels;
- more efficient vehicles; and
- smart driver choices.

Cleaner fuels

10. It is important to consider all fuels based on their life-cycle CO_2 emissions. From the “well” (or the equivalent energy source) to the “wheel”, different fuels result in CO_2 emissions at different stages of their production, transport and use. Even conventional fuels, such as petrol and diesel, can be produced in a variety of ways, with very different CO_2 impacts.

11. Biofuels, in moderation, offer potential advantages over conventional fuels and can occupy part of the transport fuels market over the medium term. But an over-reliance on biofuels, particularly in these early stages, could be counter-productive, putting the world's environmental resources under pressure. Globally, care needs to be taken not to over-expand biofuels demand before technological improvements and comprehensive sustainability safeguards are in place.

12. In the long term, carbon-free road transport fuel is the only way to achieve an 80-90 per cent reduction in emissions, essentially “decarbonisation”. Given biofuels supply constraints, this will require a form of electric vehicle, with novel batteries, charged by “zero-carbon” electricity (or, possibly, hydrogen produced from zero-carbon sources).

[4] *The Eddington Transport Study*, 2006.

13. Clean cars are dependent on clean power and, as the world moves towards electric vehicles, countries' road transport CO_2 emissions will increasingly be determined by the composition of their power generation sector. Major changes in power generation therefore need to be delivered alongside the automotive technologies. Making progress on decarbonising power generation represents an even more urgent challenge than electric vehicle technologies because of the time it takes to implement. It is essential to take a system-wide perspective and to consider displacement effects and competition for power across sectors: ultimately, decarbonisation of road transport will require decarbonisation of power generation.

More efficient vehicles

A number of technologies are close to market

14. In the nearer term, considerable CO_2 savings can be achieved through enhancements to conventional vehicle systems. Technology that can reduce CO_2 emissions per car by 30 per cent (on a like-for-like basis) is already close to market and could be standard within 5-10 years. Despite the likely vehicle cost increases (estimated at £1,000-£1,500 per new vehicle), many of these changes are likely to represent good economics to the purchaser, as a result of their impact on fuel economy. However, demand-side and supply-side barriers are currently delaying their deployment. Ensuring these technologies are quickly brought to market constitutes a major policy challenge and will have a major impact on emissions reductions from road transport in the coming years.

15. Cars that emit 50 per cent less CO_2 per kilometre than the equivalent current models could be on the road by 2030, subject to advances in hybrid and battery technologies and industry overcoming cost barriers. Longer term, vehicle technologies to enable a 90 per cent reduction in per kilometre emissions, most likely based on battery-electric propulsion systems, are feasible. Achieving this maximum benefit, however, is dependent on very low-CO_2 power generation.

16. UK industry currently has strengths in engine manufacture, and high-tech vehicle and systems design and consultancy. There are opportunities for the UK to develop further in both licensing and supplying low-carbon technologies to the mass-market manufacturers, and as a leader in some areas of the electric vehicle market. Long term, with the right approach now, the UK could play a strong role in future electric systems, novel battery and energy storage solutions and in other areas such as biofuels development.

Smart driver choices

17. Technology achieves nothing if it is not adopted. Consumers must be engaged in order to reduce substantially CO_2 from road transport. The Review estimates that savings of around 10-15 per cent could come from consumer behaviour, much of this over the next few years. Many small things can have a significant cumulative impact:

- demanding new technologies: choosing the most fuel-efficient model in the range or market sector can substantially reduce CO_2 and, critically, ensure low-carbon technologies are brought to market earlier. Downsizing vehicles would save much more;
- making the most of technologies: simple aspects of driver efficiency (for example, keeping tyres pumped up, controlling acceleration and not carrying unnecessary weight) make several percentage points difference to fuel consumption; and
- small reductions from avoiding low-value journeys, use of alternative means of transport, and more car sharing, would reduce emissions as well as congestion.

18. Not only would these choices be positive for the environment, they would also benefit the individual, reducing the amount spent on fuel. However, there remain strong barriers to realising this potential. Environmental awareness and action in road transport tend to lag other sectors. People tend to discount heavily (or not take into account) future cost savings from fuel economy at the time of purchasing a car, even though it would seem to be in their own interests as well as those of the environment. Public transport provision and road infrastructure policy can also play an important role in efficiently allocating demand for transport.

A role for everyone

19. In achieving CO_2 reductions in all areas, everyone has a part to play: consumers, fuel companies, vehicle manufacturers, the power generation and agricultural sectors, businesses and the Government.

The UK can lead by example

20. The overall challenge will require progress at a global level: the UK is responsible for only 3 per cent of global road transport CO_2 emissions and fuel and vehicle manufacturers make decisions for an international market. Achieving international consensus and co-operation is essential in many areas. The UK can and should lead by example, demonstrating through sound policies that economic prosperity and carbon responsibility can be mutually supportive. The UK should also take a lead in discussions at European and international levels.

21. Additionally, some aspects, particularly consumer choices, can be more directly influenced at a national or local level. In the UK, Government has already taken steps to support progress, through road transport taxation, R&D support, public procurement, information provision and regulation.

22. The challenge is large – but achievable if progress is made now across fuel technologies, vehicle technologies and behaviours. In 2008, the King Review Part II will offer policy recommendations on what more can be done to meet this challenge.

1 The challenge for road transport

KEY MESSAGES

1.1 Over the coming decades, road transport will continue to be a critical component of human mobility and economic growth around the world. Faced with the global challenge of climate change, it is essential and urgent to support continuing road transport and economic growth in a sustainable, environmentally responsible way. In doing this, opportunities for the UK economy should be maximised.

1.2 The Stern Review on the Economics of Climate Change sets out the overall environmental challenge. Stern estimates that the developed world, including the UK, needs to lead the way by achieving total emissions reductions of 60-80 per cent by 2050.

1.3 To meet the climate change challenge, the road transport sector will need to play its part and the UK and the rest of the already-developed world will need to lead by example, both by achieving substantial reductions in emissions and by co-ordinating international action.

1.4 This Review's analysis indicates that, by 2030, emissions per kilometre could be around 50 per cent below 2000 levels in the UK. This would be partly offset by projected growth in kilometres travelled, implying overall cuts UK emissions from car use of approximately 30 per cent by 2030. In the long-term (possibly by 2050 in the developed world), almost complete decarbonisation of road transport is a realistic objective.

1.5 This is a major challenge: urgent and sizeable. But it is achievable with strong action now. Even in the short term, we can achieve significant reductions in CO_2 emissions through use of technologies that are already available and by making smart choices.

1.6 This Review sets out this potential for meeting the road transport challenge. It focuses on cars and vans, looking at the contribution that can be made to reducing emissions from cleaner fuels, more efficient vehicles and smarter consumer choices. It identifies the key policy challenges to be considered in Part II of the King Review, due to report in 2008.

INTRODUCTION

Road transport is fundamental to growth and mobility

1.7 Road transport has revolutionised the way the world operates. In 1908 Henry Ford produced the Model T, the first mass-produced motor vehicle. Over the subsequent 100 years, road transport has radically enhanced mobility, economic prosperity and quality of life for billions of people. The Eddington Transport Study set out in detail the mechanisms by which transport feeds through to economic performance. In the future, as the world continues to develop, road transport use will undoubtedly expand, bringing with it even greater benefits.

Box 1.1: Key points from the Eddington Transport Study

Transport is integral to economic performance, regionally and globally. It makes a significant contribution both to GDP and to welfare.

Transport needs to be an integral part of a pro-environment, pro-growth strategy

Public transport provision and road pricing provide important ways of efficiently managing demand for transport.

Under a business-as-usual scenario, road transport in the UK is projected to rise by 28 per cent between 2003 and 2025.

1.8 Technological progress has been fundamental to furthering the universal objectives of growth and mobility. It has also enabled a major, global industry to prosper in its own right. In 2006, over 60 million motor vehicles were produced and sold globally, 1.5 million, or 2.5 per cent, of those having been manufactured in the UK. Annually, the UK automotive sector contributes £9 billion added value to the economy, employing 210,000 people[1].

Carbon responsibility is now crucial

1.9 For 100 years, the automotive industry has delivered technological solutions to that have enhanced economic growth and personal mobility. With the urgent challenge of climate change, it is now also necessary that carbon responsibility becomes a priority, if the industry, and, in the longer term, the global economy is to continue to prosper. The global challenge is to accommodate increases in road transport use, realising the benefits from enhanced growth and mobility, in a sustainable, environmentally-responsible way. Just as technology has helped achieve radical improvements in vehicle performance and safety since 1908, industry is now addressing its greatest challenge yet: delivering environmental solutions.

THE CHALLENGE OF CLIMATE CHANGE

1.10 The Stern Review sets out a compelling argument for strong, urgent action against climate change. Climate change, caused by greenhouse gas emissions, risks severe impacts on growth and development. Rising temperatures give rise to risks of droughts and floods, ecosystem destruction and population displacement on an unprecedented scale.

Climate change is a huge market failure

1.11 Climate change is market failure on the greatest scale the world has seen[2]. It results from the fact that the costs of greenhouse gas emissions are not paid for by those who create the emissions. The climate change externality is global in its consequences: its impacts are long-term and persistent, with a risk of major, irreversible changes. Hence there is a need for urgent, co-ordinated global solutions, as well as national efforts.

1.12 The economics in favour of action are clear. The Stern Review estimates that, without action, the overall costs and risks of climate change will be equivalent to losing between 5 per cent and 20 per cent of global GDP in perpetuity. In contrast, the overall costs of action can be limited to around 1 per cent of global GDP each year, provided action starts early. Because CO_2 is stable and builds up in the atmosphere over time, a tonne of CO_2 saved now is of greater value than a tonne of CO_2 saved later.

[1] *A study of the UK automotive engine industry*, DTI, 2006.

[2] *Stern Review on the Economics of Climate Change*, 2006.

Box 1.2: Findings of the Stern Review

Climate change attributable to greenhouse gas emissions threatens the basic elements of life for people around the world:

- on current trends, global temperatures will be 2-3 degrees Celsius higher by 2050; and
- this is likely to lead to severe impacts including floods, droughts, population displacement, ecosystem destruction and malnutrition.

The benefits of strong, early action on climate change outweigh the costs.

To achieve CO_2 stabilisation below 550ppm, the world needs to reduce total emissions by at least 25 per cent by 2050. Ultimately, stabilisation will require global emissions cuts of 80 per cent relative to current levels.

Developed countries, including the UK, will need to contribute most, given economic and population growth elsewhere. Stern suggested that developed countries like the UK will need to achieve a 60-80 per cent reduction in total emissions by 2050.

The investment that takes place in the next 10-20 years will have a profound effect on the climate in the second half of this century and in the next.

Policy to reduce climate change should be based on three elements: carbon pricing; technology policy; and removal of barriers to behavioural change.

1.13 To achieve CO_2 stabilisation below 550 parts per million (an upper limit for substantially reducing the risks of the worst impacts of climate change) annual global emissions need to be reduced by at least 25 per cent. At the 2007 G8 summit in Heiligendamm, an ambition of a 50 per cent reduction in global emissions by 2050 (relative to 1990 levels) was agreed. Given growth in other parts of world, the Stern Review states that the developed world will need to achieve cuts of 60-80 per cent by 2050.

Leading by example across all sectors

1.14 The UK is responsible for around 2 per cent of global CO_2 emissions but the Government has recognised the importance of leading by example across all sectors:

- in the household sector, there are ambitions for all new homes to be carbon-neutral by 2016;
- energy-intensive businesses face incentives to reduce emissions through Climate Change Agreements and the EU Emissions Trading Scheme;
- the Renewables Obligation marks a commitment to move towards low-carbon sources of power generation; and
- this Review is an indication of the Government's commitment to reducing carbon emissions from road transport.

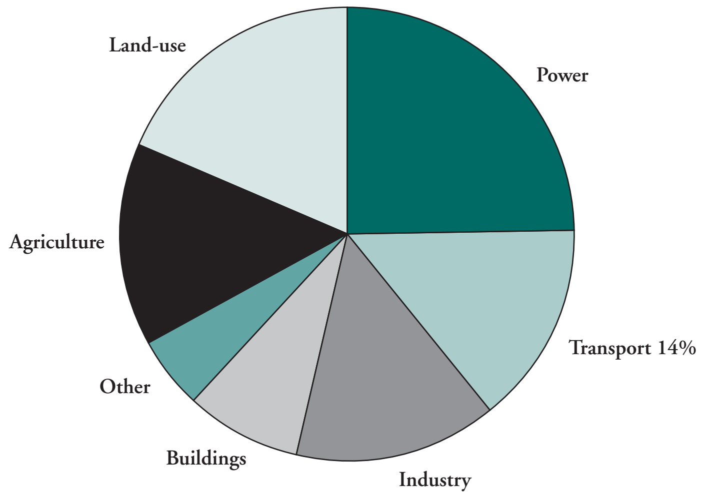
THE CHALLENGE FOR ROAD TRANSPORT

The global road challenge

1.15 A challenge on the scale set out by Stern requires all sectors, including road transport, to make urgent, substantial progress in reducing CO_2 emissions. This is why, in Budget 2007, the Chancellor of the Exchequer set up the King Review to "examine the vehicle and fuel technologies that, over the next 25 years, could help to de-carbonise road transport, particularly cars."

1.16 Globally, transport makes up 14 per cent of world CO_2 emissions, as Chart 1.1 illustrates. Cars and vans contribute 45 per cent (and road transport as a whole 76 per cent) of total transport emissions, the equivalent of 3Gt of CO_2 per year[3], as shown in Chart 1.2.

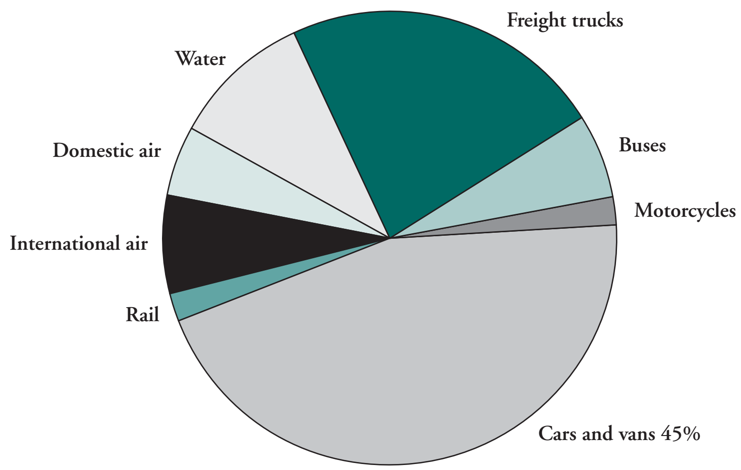
Chart 1.1: Sectoral contributions to global greenhouse gas emissions in 2000



Total emissions in 2000: $42GtCO_2e$
Energy emissions are mostly CO_2

Source: WRI (2006).

Chart 1.2: Global transport CO_2 emissions by mode in 2000



Source: WBCSD (2004).

[3] *Stern Review on the Economics of Climate Change*, 2006.

1.17 As the Stern Review recognised, transport, on a global scale, is a difficult sector in which to achieve emissions reductions, because of the projected increases in demand.

Globalisation will increase use of road transport

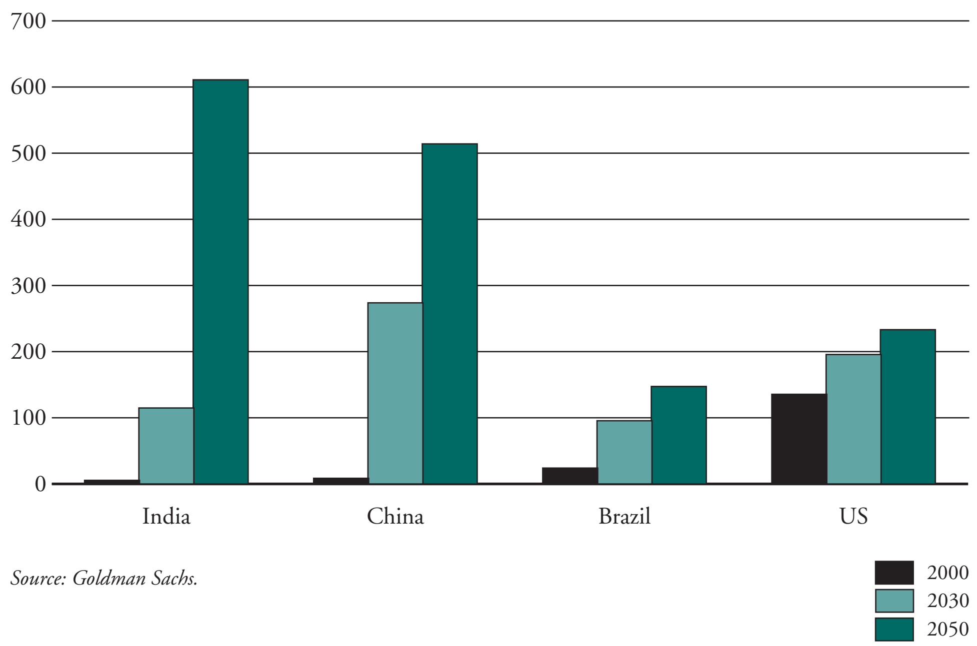
1.18 The process of globalisation and economic development in recent decades has been supported by a growing and innovative transport sector[4]. A similar story is anticipated in today's developing and emerging economies. China and India (with a total population of 2.5 billion, three times that of the EU and US combined[5]), are expected to double their share of world income in the next ten years[6] and rapid growth of road transport in those countries is set to play a key role in supporting that growth. Car ownership in China has doubled in the last five years and it already has the third highest car sales in the world. As shown by Table 1.1 and Chart 1.3, car ownership in China and India is currently a fraction of that in developed countries such as the US and UK. Over the coming decades, as these and other emerging economies grow, a very rapid rise in car ownership is projected[7].

Table 1.1: Projection of car ownership per 1,000 people

	India	China	Brazil	US
2000	5	7	137	480
2030	81	188	429	538
2050	382	363	645	555

Source: Goldman Sachs.
The BRICs and Global Markets: Crude, Cars and Capital, Goldman Sachs Global Economics Paper No. 118, 2004.

Chart 1.3: Projections of total cars owned (millions)



Source: Goldman Sachs.

[4] *Eddington Transport Study*, 2006.
[5] *The World Factbook 2006-2007*, CIA.
[6] *Long-term opportunities and challenges for the UK: analysis for the 2007 CSR*, 2006.
[7] *The BRICs and Global Markets: Crude, Cars and Capital*, Goldman Sachs, 2004.

1.19 The growth of China and India, and continued economic growth in the world more generally, will compound the challenge of reducing CO_2 emissions in road transport. The World Resources Institute is projecting that, in the absence of mitigating policy, global transport CO_2 emissions will almost treble by 2050. Consequently, to achieve Stern's environmental ambitions, while recognising the importance of increasing global mobility and economic output, and the associated increase in road transport use, it will be necessary to achieve very large reductions in average emissions (CO_2 per kilometre travelled) by 2050, on the way towards almost complete decarbonisation of road transport.

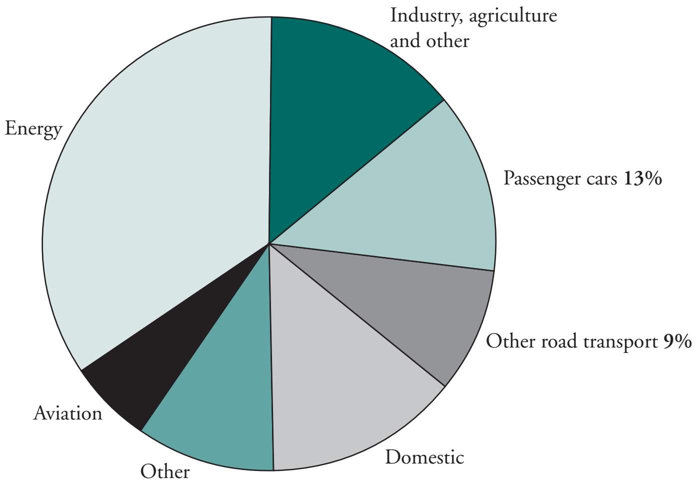
The UK road challenge

Emissions reductions of 80 per cent are possible

1.20 As in all sectors, the developed world needs to lead the way in reducing emissions from road transport. This Review's analysis indicates that, subject to progress in the power sector and in meeting a number of vehicle technology challenges, the developed world, including the UK, could realistically aim towards reducing total road transport emissions by 80 per cent by 2050 (relative to 2000).

1.21 In the UK, as in other developed countries, road transport emissions comprise a larger overall share of national CO_2 emissions relative to the global average. As Chart 1.4 shows, around 22 per cent of UK emissions (equivalent to 33Mt of CO_2) were from road transport.

Chart 1.4: Sectoral contributions to UK CO_2 emissions in 2005



Source: AEA/DEFRA

1.22 An 80 per cent reduction in road transport emissions in the UK would be a huge challenge in itself, but it is made even greater by the fact that overall road transport use is projected to increase. The Eddington Review projects a 28 per cent increase in vehicle kilometres travelled between 2003 and 2025 under a business-as-usual scenario. Given continued economic growth, road transport use is likely to continue growing beyond 2050.

Per-kilometre emissions could be 90% lower

1.23 Based on current trends, road transport use could plausibly double by 2050. This places even greater importance on improving the carbon-efficiency of road transport. For example, this would imply that achieving an 80 per cent reduction in total road transport emissions would need the average level of emissions (CO_2 emitted per kilometre travelled) to be cut by 90 per cent.

1.24 Progress is needed now, to achieve early emissions reductions; and to tackle long-term technology barriers. The Review's modelling indicates that, by 2030, vehicle emissions per kilometre could be 50 per cent below 2000 levels if substantial progress is made in delivering cleaner fuels, more efficient vehicles and smart consumer choices. Given projected growth in road transport use, this would imply cuts in total UK emissions from car use of approximately 30 per cent by 2030.

The challenge is large, but achievable

1.25 This presents a series of challenges that are large and pressing. However, this Review shows that they are achievable subject to substantial progress on a number of fronts, through cleaner fuels, more efficient vehicles and better-informed and more environmentally and economically aware consumer choices.

1.26 Even in the short term, much more could be achieved, through current technology and responsible choices:

- vehicle technologies that can reduce new car emissions by around 30 per cent are already close-to-market;
- choosing the "best in class" vehicle in today's market would reduce emissions by an average of 25 per cent; and
- following some straightforward efficient driving techniques, such as those set out on the Department for Transport's website, is estimated to reduce emissions by around 10 per cent.

Market failures in road transport

1.27 There is significant potential for emissions reduction but there are also some challenging barriers to be overcome. As previously discussed, climate change is the largest market failure the world has known. In addition, there are number of issues specific to road transport, which may delay progress or have important knock-on impacts. These are set out in Box 1.3.

Box 1.3: Potential market failures and knock-on impacts in road transport

- barriers created by large fixed costs in fuel production and vehicle manufacturing, sunk costs and the efficient scale for bringing new technologies to market (Chapter 4);
- spillover effects in the research and development of new technologies that can influence the path to market (Chapter 4);
- gaps in understanding and information that may lead to sub-optimal behaviours. On the consumer side, this could include a lack of awareness of the potential financial benefits of low-carbon technologies, concern over early adoption of new technology or uncertainties about new vehicle models (Chapter 5). For vehicle and fuel companies, decision-making and investment can be affected by uncertainty over future policy directions (Chapters 3 and 4);
- the importance of the vehicle manufacturing and fuels sectors in contributing to the UK's economic growth and employment objectives (Chapters 3 and 4); and
- impacts on other policy objectives. For example, it is important to ensure that the path followed on fuel technologies is consistent with government's approach to wider energy policy, agriculture and global development (Chapter 3).

1.28 The remainder of this chapter sets out the scope of this Review and the structure of this report.

SCOPE OF THE REVIEW

1.29 This report sets out the potential for reducing carbon dioxide emissions from road transport in the UK, in order to address the global environmental challenge.

Policy conclusions will follow in the next report

1.30 This report examines the scale of CO_2 reductions that are possible, the extent to which different sectors and agents can contribute, and the technologies and behaviours that can help. It concludes by setting out the key policy issues that need to be considered but does not propose policy solutions at this stage. Part II of the King Review, to be published in 2008, will set out clear recommendations to Government on ways to resolve some of the key policy issues.

1.31 The Review focuses predominantly on cars (and small vans, which share common technology). Globally, these account for 70 per cent of road transport CO_2 emissions. Cars and car ownership are a significant badge of the world's economic success: an individual's choice of model typically has a strong emotional element, making cars, in many ways, the most challenging area for emissions reduction. Although the scope of this Review is restricted to cars and vans, it is also important that progress is made in respect of trucks, buses and other forms of road transport.

1.32 The Review focuses primarily on the UK context, recognising that developed countries like the UK must lead the way in reducing CO_2 emissions and in demonstrating that carbon responsibility and economic prosperity can be mutually supportive. However, the UK accounts for just 3 per cent of global CO_2 emissions from transport. Early, local action is not enough unless combined with the leadership that ensures others act too, particularly as many of the technological solutions are only viable on an international scale. The Review looks at the global challenge and stresses the importance of finding solutions that will work not only at the domestic level, but also in other EU and global economies.

The Review looks beyond a 25-year horizon

1.33 This Review was set up to examine the technologies that could contribute to “decarbonising” road transport over the next 25 years. While complete decarbonisation of road transport is not likely within this time period, this document sets out a realistic ambition for 2030 that would constitute good progress for the UK in the context of a longer-term goal of effectively eliminating CO_2 emissions from vehicles close to zero.

1.34 This Review focuses primarily on the challenge of reducing CO_2 but its analysis (and ultimately the policy recommendations that will follow) is underpinned by recognition of the need to achieve this in a manner consistent with other policy priorities:

- wider environmental impact – as well as the impact of carbon dioxide emissions, it is important to consider the implications on other greenhouse gas emissions, local air quality and global biodiversity (as Box 1.4 illustrates);
- mobility and growth objectives –- as has already been discussed, transport is fundamental to the efficient functioning of the economy;
- UK business interests – as we set out in Chapter 4, road transport is a source of substantial UK business interest, for fuel and vehicle technologies. Wherever possible, environmental progress should be to the benefit of these interests;
- people's preferences – road transport enhances the lives of billions the world over and solutions need to reflect what people want;

- energy security requirements – given the likelihood of continued global uncertainty and insecurity[9], it is important to reduce the risks associated with sourcing our fuels;
- cost-effectiveness and other sectoral objectives - there are major overlaps between road transport and other sectors such as power generation and agriculture and any strategy needs to take into account these wider implications. What is best for transport may not be best for the economy as a whole; and
- international development goals – road transport will be important for growth in developing countries, and new fuel technologies will have impacts on global markets.

[9] *Long-term opportunities and challenges for the UK: analysis for the 2007 CSR*, 2006.

Box 1.4: The focus on CO_2 emissions

CO_2 and other greenhouse gases

CO_2 is one of a number of greenhouse gases (the contributors to climate change) associated with road transport. For example, nitrogen oxides (NO_x), which are released from car exhaust pipes, soil conversion and production use of fertiliser, are around 300 times as potent as CO_2 in terms of their impact as greenhouse gases. Methane is 21 times as potent as CO_2.

For the purpose of this Review, unless stated otherwise, CO_2 is used as a generic term for all greenhouse gas emissions – it is based on a "CO_2 equivalent" measure, with weights applied to reflect the potency of other greenhouse gases.

Air quality

A number of the harmful emissions associated with road transport, including hydrocarbons, NO_x and carbon monoxide, are detrimental to local air quality. This cannot be ignored, and in some cases there can be trade-offs:

- standard diesel currently results in lower CO_2 emissions but higher NO_x emissions than gasoline; and
- ethanol is generally a cleaner-burning fuel than gasoline, producing less CO_2, but results in higher concentrations of sulphur dioxide and other local pollutants.

However, in many cases, CO_2 and other harmful emissions will tend to decline together, Even where trade-offs occur, because of the much larger amounts of CO_2 generated in combustion of carbon-based fuels, the CO_2 impact will normally be dominant.

1.35 The Review builds on Sir Nicholas Stern's Review on the Economics of Climate Change, as well as recent government and industry documents and strategies for low-carbon transport. It is also informed by a substantial stakeholder engagement programme. Professor Julia King and her Review Team have met people from across the world; in governments, academia, the automotive, fuels and materials industries, professional institutions and trade associations, environmental groups and other non-governmental organisations. This document also contains evidence and insights submitted to the Review's Call for Evidence, which elicited almost 100 responses.

STRUCTURE OF THIS DOCUMENT

1.36 An achievable scenario for the developed world, and specifically the UK, is a reduction in total emissions from road transport by 30 per cent by 2030, which would constitute good progress towards meeting the environmental challenge laid down by the Stern Review. This document sets out the elements that can contribute to realisation of this scenario, as well as looking further ahead to what is required to achieve almost complete decarbonisation of cars.

1.37 Chapter 2 provides a framework for considering CO_2 efficiencies across the system, from the point at which fuel is sourced, to the efficiency of vehicle technologies and the impact of driver choices. Subsequent chapters set out the areas of potential CO_2 reductions to meet the overall ambition:

- cleaner fuel technologies (Chapter 3);
- more efficient vehicle technologies (Chapter 4); and
- smarter driving choices (Chapter 5).

1.38 Chapter 6 provides an indication of the CO_2 efficiencies that could be achievable from these areas and discusses a possible pathway to achieving the overall ambition.

1.39 Chapter 7 concludes the key messages from the analysis and sets out the policy challenges that will be addressed in Part II of the King Review, in 2008.

2 Framework for assessing CO_2 emissions from cars

INTRODUCTION

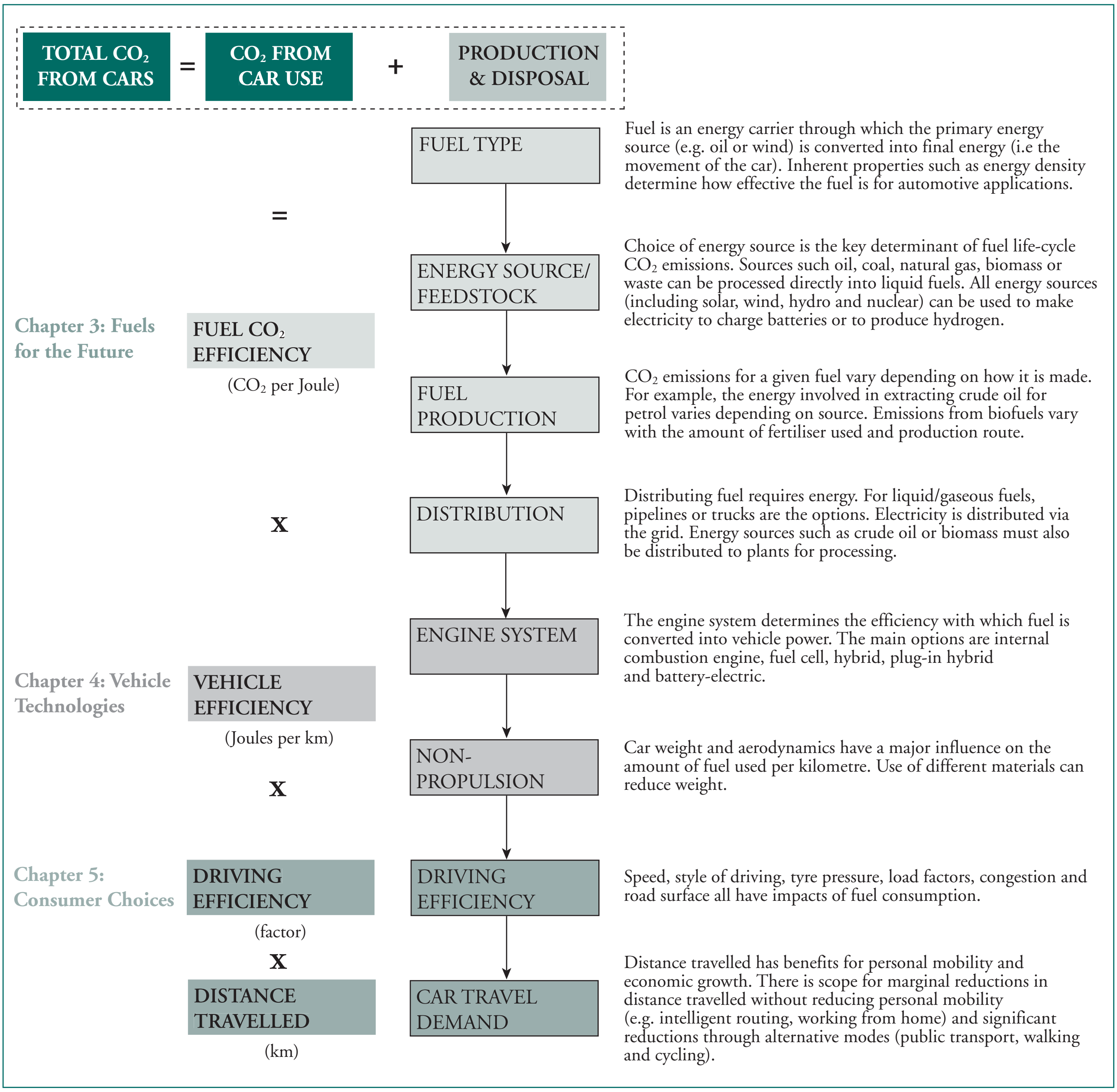
2.1 This chapter sets out a framework for considering the total CO_2 emissions from cars. There are four key factors that determine the total CO_2 associated with car use and where there is significant scope for emissions reductions:

- fuel CO_2 efficiency;
- vehicle efficiency;
- driving efficiency; and
- distance travelled.

2.2 Combined, these factors account for emissions from car use. There are also non-use CO_2 emissions from the manufacture and disposal of the cars, and from car and fuel production infrastructure.

2.3 The rest of this chapter outlines the framework for assessing CO_2 emissions from cars in more detail and explains how this fits with the rest of the report.

CAR CO_2 FRAMEWORK



Fuel CO_2 efficiency (CO_2 per Joule)

Box 2.1: Use of the term "fuels" in this Review

Fuels here are "energy carriers" that convert primary energy sources (e.g. crude oil, coal, nuclear, wind and biomass) into final energy (i.e. the movement of the car). There are many different ways of making the same fuels, involving different primary energy sources, often in combination. In particular, hydrogen and electricity can be produced from the full range of primary energy sources.

2.4 The carbon efficiency of a fuel refers to how much CO_2 is associated with each unit of energy stored in the fuel. It must therefore take account of CO_2 emitted across the whole life cycle of the fuel including:

- extraction/farming of the primary energy source (for example, extracting crude oil from wells to make petrol or farming crops to make biofuels);
- transport of primary energy sources to fuel production/processing plants;
- production/processing of the energy source into the final fuel;
- distribution of the fuel to cars; and
- the use of the fuels in the car (tailpipe emissions).

2.5 All these stages of the life cycle can have significant CO_2 emissions associated with them and, therefore, offer potential scope for savings. By adding all these emissions together the CO_2 per unit of energy delivered to the car engine can be determined. Petrol and diesel are currently the dominant fuels and CO_2 emissions could be reduced by using alternative fuels that have lower life-cycle CO_2 emissions. Chapter 3 addresses how the CO_2 efficiency of fuels can be improved across their whole life cycle.

Vehicle efficiency (Joules per km)

2.6 "Vehicle efficiency" refers to how efficiently a vehicle converts the energy contained in the fuel into propulsion. There are many factors that affect this including the efficiency of the engine or propulsion system, the weight of the car and its aerodynamics. The internal combustion engine is currently the dominant engine and there is still significant scope to improve its efficiency and to use other more efficient vehicle technologies such as hybrid systems and lighter materials.

2.7 Vehicle efficiency and fuel CO_2 efficiency are interdependent as the type of vehicle largely determines the fuel that can be used. Chapter 4 addresses how improving vehicle efficiency can contribute to reducing CO_2 from cars.

Driving efficiency (efficiency factor)

2.8 "Driving efficiency" refers to the efficiency with which the driver uses the car to drive a given distance. In other words, how close is the driver to the "ideal driver" (operating at the vehicle's "design point" or to some optimum driving cycle) and how close are driving conditions to the optimum (for example taking into account congestion levels). There are a number of areas where driving efficiency can be improved: for example, through smoother driving (minimising the energy lost through accelerating and braking), by carrying less unnecessary weight in the car, and by preventing excess drag. Travelling during non-congested periods and reducing maximum speed on motorways also improves driving efficiency. Chapter 5 addresses driving efficiency in more detail.

Distance travelled (km)

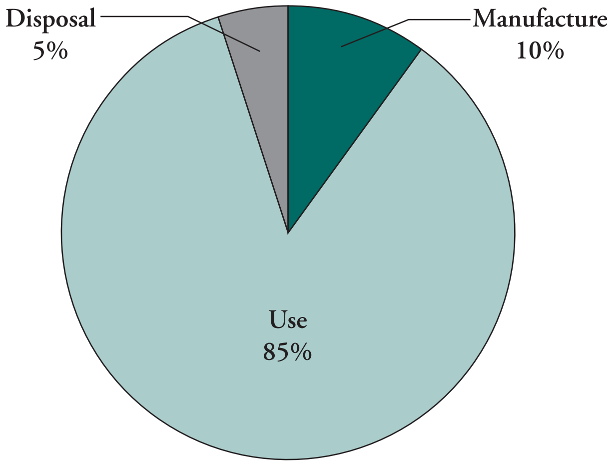
2.9 Fuel, vehicle and driving efficiency determine the amount of CO_2 emitted per kilometre driven. These are combined and multiplied by the distance travelled to determine the total CO_2 from car use. Kilometres travelled, and therefore CO_2 emitted, can be reduced in many ways.

2.10 Demand for road transport is expected to rise in the future. This will bring benefits for personal mobility and economic growth. For these two reasons, it will generally be preferable to reduce CO_2 by improving fuel, vehicle and driver efficiency rather than by reducing demand for travel. Although Chapter 5 identifies instances where distance travelled can be reduced without impinging on personal mobility (for example, by using alternative forms of transport or by car-sharing), the main focus of this Review is on the technological potential to improve fuel, vehicle and driving efficiency.

Production and disposal

2.11 The last factor in the total CO_2 from cars equation is the CO_2 emitted from car manufacture and disposal. As Chart 2.1 shows, this is currently a small percentage of total emissions (approximately 15 per cent). However, as CO_2 emissions from car use decline, this will become a more important consideration.

Chart 2.1: CO_2 emissions through the vehicle life cycle



Source: SMMT (2007).

3 Fuels for the future

KEY MESSAGES

3.1 To take full account of the carbon impact of different fuels, each fuel must be considered across its complete life cycle. There are many different ways of producing the same fuel, resulting in markedly different life-cycle CO_2 emissions. Therefore, reducing CO_2 emissions from the way fuels are produced is as important as influencing which fuels are used.

3.2 Biofuels are likely to play a significant and growing role in road transport. Ensuring the sustainable development of biofuels is critical – production must not be expanded ahead of advances in technology and the development of robust safeguards to minimise their environmental and social impacts. Currently, land requirements of biofuels are high and rapid expansion of production risks adverse environmental impacts from changing land use, as well as increased food prices. However, future biofuel technology has great potential to reduce land and water requirements and deliver much greater CO_2 savings.

3.3 Over the longer term, the extent to which road transport can be decarbonised is likely to be dependent on the degree to which CO_2 emissions from electricity generation can be reduced. The use of electricity to power cars (either to charge electric car batteries or to produce hydrogen) is likely to become much more important, because petrol and diesel are inherently polluting and biofuels have a limited capacity. This will place extra demand on electricity generation, so ensuring this is supplied from low-CO2 sources is another major challenge.

INTRODUCTION

3.4 This chapter focuses on alternative fuel technologies and how they can contribute to reducing CO_2 emissions associated with car use. Alternative fuels are not new: the original Model T was designed to run on petrol or ethanol. Since then petrol and diesel have been the dominant automotive fuels. However, with climate change an increasing challenge, the pressure to use low-CO_2 alternatives to petrol and diesel is increasing. Options include electricity, hydrogen, biodiesel and, as Henry Ford originally envisaged, ethanol. The switch towards alternative fuels will bring both challenges and opportunities, particularly as it necessitates closer collaboration between the transport sector and other industries such as agriculture and power generation.

3.5 This chapter begins by introducing the major fuel types and assesses how they compare to the "ideal" fuel. The life-cycle emissions of these fuels are considered, emphasising the importance of the route by which a fuel is produced. The chapter then considers the importance of understanding links between transport fuels and other sectors, such as power generation and agriculture.

3.6 The second part of the chapter looks towards fuels in the future. In particular, it considers the potential capacity of the biofuels industry and the issues associated with expanding production. The likely nature of the fuel mix in 2030 is discussed, along with the opportunities this could provide for UK businesses.

FUEL TYPES

What makes a good fuel?

3.7 A number of properties determine what makes a "good" fuel for use in private cars. The ideal fuel is:

- energy dense for maximum range and able to provide fast and convenient refuelling of the vehicle;
- easily storable and transportable;
- stable over a wide range of temperatures;
- non-damaging to the car engine;
- inexpensive to produce and distribute;
- available from secure sources;
- not detrimental to local air quality; and, critically,
- low-CO_2 over its life-cycle (in production, distribution and use).

3.8 In general there are trade-offs between these criteria, creating challenges for fuel suppliers and policy-makers. For example, fuels that are currently relatively inexpensive, such as petrol and diesel, often have relatively high CO_2 emissions over their life-cycle.

3.9 There is a large number of different fuel types (and sub-types) that could be used to power a car. Moreover, there are often several different ways of producing the same fuel (using different primary energy sources and production techniques). For example, petrol is commonly produced from crude oil but it can also be produced from coal – resulting in very different CO_2 impacts. Box 3.1 gives an overview of some fuel types, and the remainder of this section focuses on fuel types of particular interest: petrol, diesel, biofuels, electricity and hydrogen.

Box 3.1: Overview of some key fuel types

Petrol is conventionally refined from crude oil although it can also be produced from unconventional sources such as tar/oil sands and coal. CO_2 is emitted through the use of petrol as well as from extracting crude oil, refining it into petrol, and distributing it to stations.

Diesel is most commonly made from crude oil (also increasingly it is being converted from natural gas). Diesel vehicles give better fuel economy than petrol and therefore lower CO_2 emissions per kilometre. Diesel has an air quality disadvantage compared with petrol, but this can be mitigated to a large degree by improved engine technologies and exhaust catalysts.

Liquid petroleum gas (LPG) is made from either natural gas or crude oil and is generally used in a dual-fuel vehicle that can also take petrol. It has slightly lower CO_2 life-cycle emissions than petrol. Limited supplies mean that LPG could never fully replace petrol or diesel.

Compressed natural gas (CNG) is natural gas stored at a high pressure. It can be distributed to refuelling stations through the natural gas grid. CNG has slightly lower CO_2 life-cycle emissions than petrol or diesel because of its chemical composition but the scale of uptake has been limited by the cost of converting car engines.

Biofuels are made from biomass such as plants or organic waste. They can be used in low concentration blends (5-10 per cent) with petrol or diesel without engine modification and in high concentrations (85-100 per cent) with specially adapted vehicles. CO_2 from burning the fuel is exactly offset by that absorbed when the biomass grows. However, there can be significant CO_2 emissions associated with the cultivation of feedstocks and production (see box 3.3). **Bioethanol** is currently made mainly from starchy crops such as sugar cane and maize and is a substitute for petrol. **Biodiesel** is currently made mainly from oily crops such as rapeseed. Other significant biofuels include **Biobutanol** and **Biogas**.

Electricity produces no CO_2 emissions at the point of use in a car. Its overall CO_2 impact depends principally on how the electricity is generated. If produced from renewable, nuclear or, potentially, fossil energy with carbon capture and storage, it can be very low-CO_2 fuel.

Hydrogen can be used in an internal combustion engine or in a fuel cell powered vehicle. It produces no CO_2 emissions at the point of use[2]. However, there are no natural sources of pure hydrogen and it must produced from water, coal, gas, crude oil or biomass. This requires energy and often generates significant CO_2 emissions. Common current ways of producing hydrogen are from steam-reforming of natural gas, gasification of coal and from electrolysis of water. Like electricity, hydrogen could be a very low-CO_2 fuel if produced with very low-CO_2 energy. However, there are significant challenges associated with transporting and storing hydrogen.

Petrol and diesel

3.10 Petrol and diesel are currently by far the dominant transport fuels for cars, representing 99 per cent of the UK fuels market[3]. They dominate because they meet most of the criteria above for what makes a good fuel. They are energy dense (see Box 3.2), easily storable, non-corrosive and tend to be inexpensive relative to the alternatives. Moreover, decades of "learning-by-doing" have helped make the production, distribution and use of petrol and diesel increasingly efficient. However, because of their chemical composition, they produce CO_2 when burned, and their production and use can have significant adverse impacts on local air quality. In addition, there are finite supplies of crude oil, and resources tend to be concentrated in a relatively small number of countries, thus creating risks around security of supply. For these reasons, while petrol and diesel are expected to play a significant role in road transport for the foreseeable future, alternative fuels will become increasingly important.

[2] Although if used in an internal combustion engine some nitrous oxide is released.

[3] *HMRC Annual Report 2004/5.*

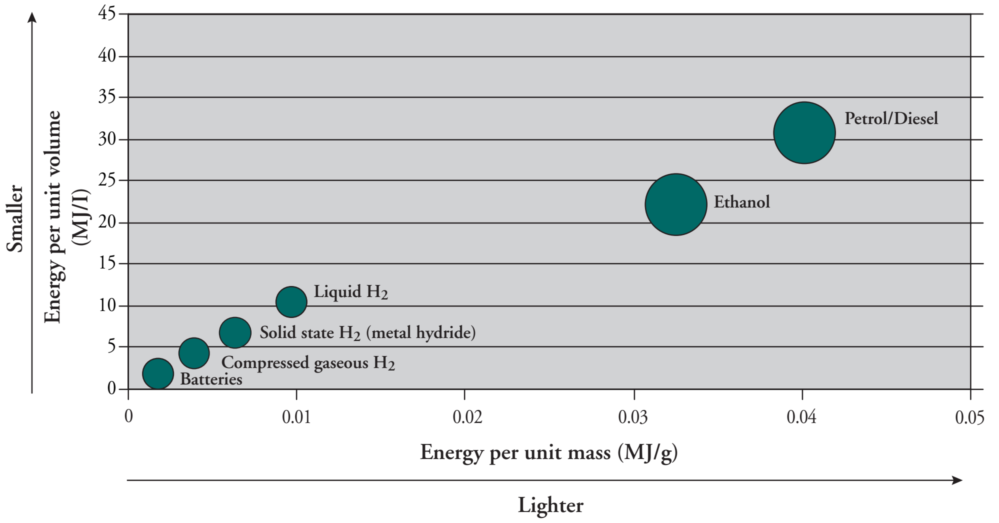
Box 3.2: The importance of energy density

Energy density is a key determinant of how effective a fuel is in a vehicle where both space and weight are at a premium. There are two aspects to this:

- the energy contained in a given mass (i.e. weight) of the fuel. A higher mass-energy density gives a better range for the vehicle, because less energy is wasted in moving the fuel itself. It can also offer improved performance by enabling a high rate of energy delivery to the vehicle; and
- the energy stored in a given volume of the fuel. A higher volume-energy density means that less space in the vehicle is taken up by the fuel, so the fuel tank or battery can be smaller, reducing vehicle size and weight or offering more usable space.

As the diagram below shows, petrol and diesel have a high volume-energy and mass-energy density compared to other fuel types, making them very good fuels from a car design perspective. Chapter 4 discusses the challenge of improving the energy density of batteries.

Chart 3.1: Illustrative energy density of some fuel types



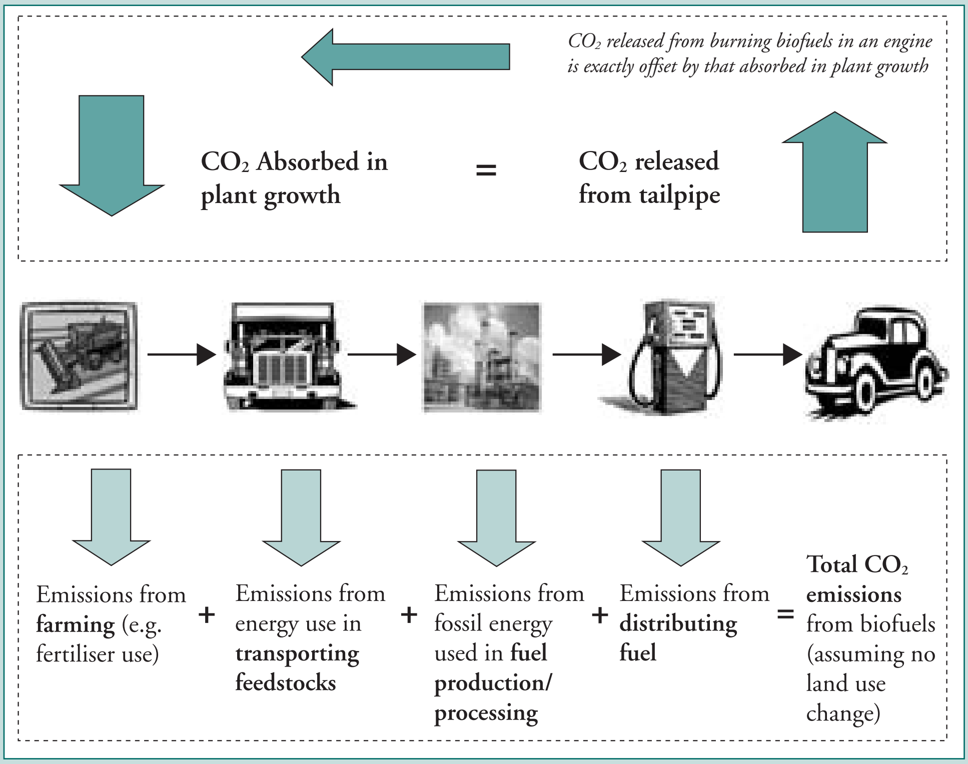
Biofuels 3.11 Liquid biofuels are an obvious alternative fuel since they can be blended with petrol or diesel and used in a conventional internal combustion engine, with some adaptation of the engine needed for blends with high biofuel levels. They generally have slightly lower energy densities than petrol and diesel, such that they sometimes offer slightly lower range when used in high blends (with the exception of biobutanol which gives an equivalent range). Once produced, biofuels are relatively easily storable and transportable and can use the existing petrol/diesel infrastructure, with blending facilities added on.

3.12 There are many different types of biofuel, with ethanol and biodiesel currently the most common. Ethanol is currently made mainly from starchy crops such as sugar cane and maize. It is generally used as a substitute for petrol and is usually blended with it. Biodiesel is generally made mainly from oily crops such as rapeseed and is a substitute for diesel. Blends of ethanol or biodiesel above 5-10 per cent need engine modification, although this is relatively inexpensive.

3.13 Biofuels can be made from a wide range of feedstocks: food crops (e.g. maize and sugar); non-food parts of crops (e.g. straw); dedicated energy crops (e.g. poplar, switchgrass and jatropha); agricultural waste; municipal waste and even algae. The importance of non-food feedstocks in expanding biofuel production sustainably is discussed later in this chapter.

3.14 Biofuels can offer significant CO_2 savings compared with petrol and diesel. These savings vary widely depending on feedstocks used, farming method and production technique. While CO_2 emissions from the tailpipe are exactly offset by those absorbed in the growing of feedstocks, there can be significant CO_2 emissions associated with farming (particularly the use of fertiliser) and the production process (see Box 3.3). Moreover, as explained in Paragraph 3.49, there are severe adverse climate change impacts if forest or grassland is cleared to provide land to grow feedstocks, because large quantities of CO_2 "locked-up" in the plants and soil are released.

Box 3.3: Where do CO2 emissions from Biofuels come from?



3.15 Biofuels offer some security of supply advantages in reducing dependence on oil-rich regions of the world. However, major dependence on biofuels could leave fuel supply exposed instead to agricultural risks such as weather, including floods and drought, and pests and diseases; as well as creating pressures on food supply.

Electricity

3.16 Electricity has many attractive properties as a transport fuel. It results in zero emissions at the point of use, giving it major local air quality benefits over petrol and diesel. Moreover, if it is produced from low-CO_2 sources, such as renewables, nuclear or, potentially, fossil energy with carbon capture and storage, it can have low or even effectively zero CO_2 emissions over its life cycle. It can also be produced from the full range of energy sources, offering major security of supply benefits. In most areas, electricity is distributed via a grid, so the basic charging infrastructure for electric vehicles is essentially in place. Since electric vehicles are powered by a battery driving an electric motor, the engine wear problems of conventional vehicles are largely eliminated.

3.17 Currently, the main drawbacks with electric cars are their relatively low speed, short range and lengthy recharging times. As Chapter 4 discusses, major developments in battery technology are needed to give performance comparable to an internal combustion engine.

Hydrogen

3.18 Like electricity, hydrogen also has attractive properties as a fuel. When used in an engine, the only significant emission is water vapour. If the hydrogen is made from low-CO_2 energy sources, very low life-cycle emissions are a possibility, although some pathways to producing hydrogen can have significantly higher life-cycle CO_2 emissions than petrol or diesel (see Paragraph 3.32). Since it can be produced from the full range of energy sources, it provides the same security of supply benefits as electricity. Hydrogen can also be produced from the surplus energy generated from intermittent renewable energy sources (such as wind, wave, tidal and solar), and then stored and used later. In internal combustion engines, hydrogen can deliver similar speed to petrol and diesel, although with current vehicle prototypes the range is shorter because of the challenge of storing hydrogen in an energy dense form.

3.19 However, there are a number of major challenges associated with the use of hydrogen as a transport fuel. First, there are no natural sources of hydrogen so it must be produced, by chemical reaction, from water, coal, oil, gas or biomass. Such processes are inherently energy-intensive. Moreover, storing hydrogen in an energy dense form presents technical challenges and the distribution infrastructure remains to be developed. More efficient routes to hydrogen production are likely to emerge, both as the electricity generating mix changes and as new technologies develop.

No fuel is perfect

3.20 The discussion above illustrates that no fuel is perfect. Different fuels have different strengths and weaknesses. However, given the urgent need to address climate change, life-cycle CO_2 emissions must become a fundamental criterion by which all fuels are assessed. The next section discusses life-cycle CO_2 emissions and costs of alternative fuels, including the significance of how they are produced.

Box 3.4: Interdependencies between fuels, infrastructure, and vehicles

Currently the car fleet and fuel production/distribution infrastructure are well set up for petrol and diesel. The switch towards alternative fuels will require some changes to infrastructure and vehicles.

Liquid biofuels can largely use existing petrol/diesel infrastructure although facilities to blend bioethanol will need to be added. At present both bioethanol and biodiesel blends above 5 per cent risk voiding engine warranties (although blends of 10 per cent for bioethanol and 7 per cent for biodiesel should be possible without significant vehicle modification). Achieving proportions of bioethanol and biodiesel beyond 10 per cent of the fuel mix will require some changes to the existing vehicle fleet (either a general increase in vehicle compatibility or increased market penetration of vehicles that can take high blends of 85 per cent and above).

Biogas/natural gas could make use of existing distribution infrastructure in the form of the national gas grid, although refuelling facilities would need to be added. Vehicles need significant modification to use gas. Biogas may be best suited to use in captive fleets and larger vehicles (such as HGVs, LGVs and buses) as they can accommodate bulky engines and fuel tanks more easily.

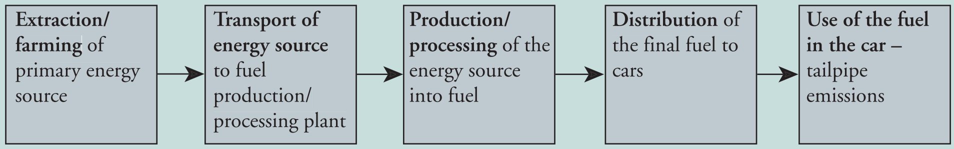
Electricity the large-scale uptake of pure electric cars requires wide availability of charging points. Given that electricity is already supplied diffusely, this should be relatively straightforward to implement. Vehicles can already be recharged from the garage or from the street using a routed cable. In addition, charging points in car parks could effectively increase range, and "fast-charging" points could help reduce recharging times.

The use of **hydrogen** cars would require major new supply infrastructure. Use of hydrogen in captive bus and car fleets (where the need for diffuse refuelling is limited) is therefore the most likely intermediate step. A large supply network is only likely to be developed if hydrogen emerges as a fuel that can be widely supplied in a low-CO_2 way and at a reasonable cost, and if developments in battery technologies do not provide a more cost-effective electric alternative.

LIFE-CYCLE EMISSIONS AND COST OF FUELS

3.21 The CO_2 efficiency of a fuel depends not only on the CO_2 released when the fuel is used or burnt in the engine (tailpipe emissions) but also the CO_2 emitted along the entire fuel supply chain. Box 3.5, below, characterises the key stages in the life-cycle of a fuel.

Box 3.5: Key Stages in the life cycle of a fuel



This Report refers to life-cycle CO_2 emissions across the extraction, transport, production, distribution and use of a fuel. There are also important interdependencies between fuel life cycles and other CO_2 life cycles, which need to be considered. For example, CO_2 emissions are associated with construction and disposal of fuel supply infrastructure, including trucks, factories and farm machinery (in the case of biofuels). In addition, as discussed in Paragraph 3.49, land-use change associated with growing feedstocks for biofuels can result in substantial CO_2 emissions from the clearing of grasslands or rainforests.

3.22 Life-cycle emissions (LCEs) are referred to in this chapter on a per-kilometre basis taking vehicle efficiency (the efficiency with which energy in the fuel is converted into automotive power) and driving efficiency as fixed.

Sources of CO_2 emissions among fuels

3.23 The distribution of CO_2 emissions through the life cycle varies greatly across the different fuel types. With conventional petrol and diesel, typically around 85 per cent of emissions are from the car tailpipe, with 15 per cent from extraction, refining and distribution[6]. In general, CO_2 emissions from biofuels mostly arise from farming of the feedstock (particularly fertiliser use) and from fossil energy used in fuel processing. There are also high tailpipe CO_2 emissions from biofuels but, since these are exactly offset by CO_2 absorbed in crop growth, they are generally characterised as zero[5]. With hydrogen[2] and electricity, CO_2 emissions at the tailpipe are zero and all emissions are generated upstream, mostly in production.

3.24 An important point with regard to liquid fuels (including petrol, diesel, ethanol and biodiesel) is that CO_2 emissions from distribution of the final fuel product are generally relatively small. For example, CO_2 emissions from distributing (and dispensing) petrol and diesel are commonly less than 5 per cent of total life-cycle emissions, even when imported, and those from distributing biofuels are similarly small.

3.25 As the world moves towards alternative fuels, with lower total CO_2 emissions over their life cycle, the dominant fuel-related emissions will move from being tailpipe emissions to upstream emissions. This will have major implications for policy-making.

[5] *Carbon and Sustainability Reporting Within the Renewable Transport Fuels Obligation – Requirements and Guidance,* Department for Transport, June 2007.

Variations in life-cycle emissions

3.26 There are many ways of producing the same fuel. The production path can have a major impact on the life-cycle emissions (and the cost) of the fuel. This is particularly true of biofuels, hydrogen and electricity, but also increasingly of petrol and diesel as new resources are exploited to meet the growing global demand for fuel.

Unconventional petrol and diesel

3.27 Conventional petrol and diesel have traditionally been refined from crude oil extracted from wells. However, increasing amounts of petrol and diesel are now being sourced from oil and tar sands, as well as coal, and these pathways are very CO_2-intensive. Petrol from oil and tar sands has life-cycle emissions that are between 15 per cent and 170 per cent higher than that from conventional sources[6]. Petrol from coal (coal-to-liquid) has around 80 per cent higher LCEs than conventional petrol, although these could potentially be reduced in future by using carbon capture and storage (CCS), or biomass co-feed to power the processing plant[7]. These CO_2-intensive sources are becoming significant sources of petrol and diesel and their use in future is set to increase. As an illustration of this, Canadian oil sands represent 14 per cent of current "proved"[8] world oil reserves[9].

Biofuels

3.28 The life-cycle emissions of biofuels vary significantly depending on how and where the fuel is produced. For example, in Europe, bioethanol from sugar beet can have LCEs that are up to 70 per cent lower than conventional petrol, although many lower-cost bioethanol pathways provide much smaller CO_2 savings. Bioethanol from Brazilian sugar cane can provide savings of at least 80 per cent[10]. In general, the main sources of emissions from liquid biofuels are from gaseous oxides of nitrogen emissions associated with fertiliser use, and fossil energy used in processing. Biogas from organic waste can actually have negative LCEs compared to a do-nothing scenario where, when left to decompose, the waste emits methane into the atmosphere (which is 21 per cent more potent as a greenhouse gas than the CO_2 emitted when burning the fuel).

3.29 Most biofuels appear to offer at least a small CO_2 saving, compared with petrol and diesel, on a year-by-year basis. However, if forest or grassland is converted to accommodate their production, there can be very large one-off releases of CO_2 (see Paragraph 3.49). For ease of calculation, life-cycle studies of biofuels generally assume no land-use change, but this can be a dangerous simplification. Moreover, even excluding land-use change impacts, there is continuing uncertainty over the life cycle calculations for biofuels (see Box 3.6).

3.30 In future, improved biofuels technology could significantly reduce the life-cycle emissions of biofuels, by allowing the crop itself to provide energy for production and by using feedstocks that require little or no fertiliser. This could deliver CO_2 savings of 80-90 per cent compared to petrol and diesel, although cost is currently a barrier. In addition, as discussed later, future biofuels could potentially offer significantly reduced land requirements, lowering the risks associated with land-use change.

Electricity

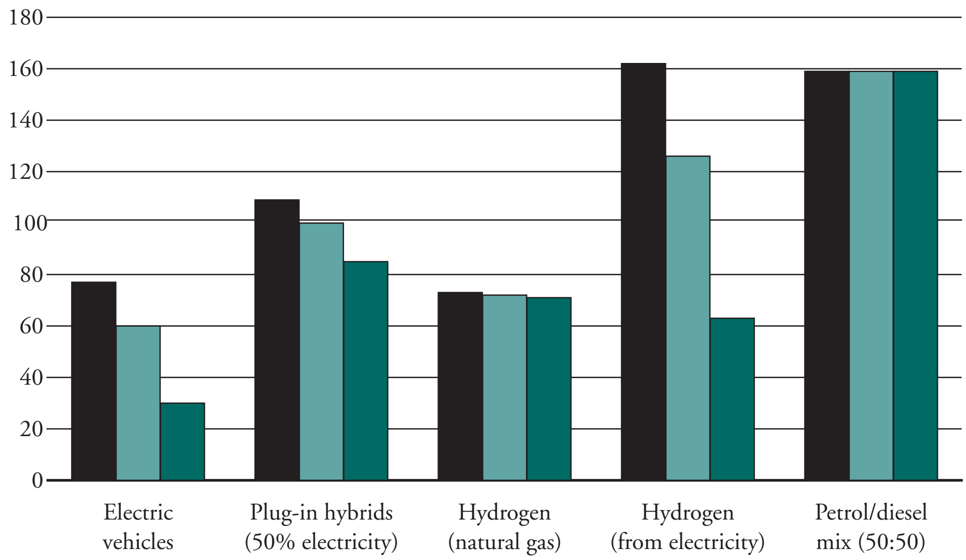
3.31 Estimates of the LCEs of electricity vary widely depending on how the electricity is generated. Comparisons with other fuels are difficult to make because of the current absence of fully electric cars with similar size and performance to petrol and diesel vehicles. However, emissions are likely to be lower than for petrol and diesel if the electricity is generated from any

[6] *A Low Carbon Fuel Standard for California, Part 1: Technical Analysis,* Institute of Transport Studies, UC Berkeley, 2007.
[7] *The Landscape of Global Abatement Opportunities – Transport sector deep-dive*, Vattenfall, 2007.
[8] "Proved" reserves are those that are "reasonably certain" to be viable using current technology and at current prices.
[9] *BP Statistical Review of World Energy*, BP, 2007.
[10] *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context*, CONCAWE/EUCAR/ECJEC, 2007.

form of primary energy, with the exception of coal. If the electricity is generated from renewable energy, such as wind power, LCEs can be, effectively, zero. Chart 3.2 provides some estimates of CO_2 emissions from electric cars and plug-in hybrids under different grid mix scenarios.

Hydrogen 3.32 There are a number of different ways to produce hydrogen, resulting in LCEs that are either greater or smaller than petrol and diesel. Using coal-fired electricity, hydrogen has 100 per cent to 400 per cent higher LCEs than conventional petrol and diesel, while LCEs of hydrogen are 90 per cent lower when using renewable or nuclear electricity[11]. When reformed from natural gas, the LCEs of hydrogen are between 50 per cent[12] lower and 20 per cent[11] higher than petrol and diesel, although in future this could potentially be improved through carbon capture and storage. Other non-electrical ways of producing hydrogen (for example, from biomass or through novel nuclear technologies) could also be very low-CO_2.

Chart 3.2: CO_2 emissions from electricity and hydrogen under different grid mix scenarios (gCO_2/km)



Source: E4tech (2007) A Review of the UK Innovation System for Low Carbon Road Transport Technologies

Grid mix *scenario A – 450 gCO2/kWh – equivalent to current grid mix.*
Grid mix *scenario B – 351 gCO2/kWh – equivalent to a new combined cycle gas turbine plant (CCGT).*
Grid mix *scenario C – 176 gCO2/kWh – increased renewables/nuclear and use of CCS with coal.*

Making fuel production cleaner 3.33 The discussion above illustrates that, as well as ensuring the right mix of fuels, reducing CO_2 from fuels also requires that the production of fuels become less carbon-intensive. There is a large number of potential ways in which the carbon intensity of fuel could be reduced along the supply chain, some incremental and others requiring a step change. Examples include:

- carbon capture and storage (CCS) to reduce the CO_2 impact of petrol and diesel made from oil sands and coal if this can be demonstrated and made cost-effective in the future;

[11] *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context,* CONCAWE/EUCAR/ECJEC, 2007.
[12] *A Review of the UK Innovation System for Low Carbon Road Transport Technologies,* E4tech, 2007.

- more CO_2-efficient farming techniques for growing and harvesting biofuel feedstocks. This might include use of feedstocks that require little or no fertiliser and those that have high levels of standing biomass (e.g. switchgrass and poplar), thereby "locking up" more CO_2;
- biofuel processing techniques that reduce the fossil energy requirement of production, including the use of biomass to provide the energy for processing; and
- low-CO_2 energy sources to make electricity or hydrogen (renewables, nuclear or, potentially, fossil energy with CCS).

3.34 The next stage of the King Review will consider how to develop the appropriate policy framework to encourage the market to make the interventions that will most cost-effectively deliver CO_2 reductions. This framework needs to encourage reductions across the life cycle of all fuels. A significant international challenge will be to establish a robust and accurate agreed methodology for measuring the life-cycle emissions of fuels (see Box 3.6).

Box 3.6: Challenges in measuring life-cycle emissions of fuels

There are significant difficulties with measuring and monitoring life-cycle CO_2 emissions of fuels, reflecting the complexity of their production and supply chains. The life-cycle emissions of biofuels are particularly difficult to measure consistently and accurately. Issues include:

- how to account for by-products such as heat and chemicals, produced alongside the fuel;
- treatment of nitrous oxide emissions associated with fertiliser use;
- the dynamics of soil CO_2 sequestration and how this is affected by the cultivation of different crops;
- whether and how to include direct and indirect land-use change impacts; and
- in a global market, with homogenous final products, it can be difficult and costly to measure across the full supply chain.

The Department for Transport is currently consulting on how to establish an agreed methodology on measuring LCEs of biofuels, and similar work is ongoing around the world.[13] California is currently developing a life-cycle methodology for all fuel types.

Establishing an agreed methodology for measuring the LCEs of fuels will be a key step towards a policy framework that cost-effectively reduces CO_2 from fuels. Moreover, given that importing of fuels is often both necessary and desirable[14], international agreement on measurement methodology, incentivisation and enforcement will be needed. Until a scientifically sound and internationally-agreed framework is in place, biofuels that appear to offer only marginal CO_2 savings should be regarded as "high risk".

Costs

3.35 Cost is a fundamental consideration when assessing the potential for alternative fuels to contribute to CO_2 reduction in road transport. As with CO_2 emissions, measuring the actual resource cost of different fuels (and ways of producing them) is difficult. This is particularly the case when allocating costs associated with capital spend and products that are generated alongside the fuel. The relative cost of alternative fuels will be subject to significant and uncertain changes in the future as technology improves and costs of primary energy sources change. Despite these

[13] *Carbon and Sustainability Reporting Within the Renewable Transport Fuels Obligation – Requirements and Guidance,* Department for Transport, June 2007.

[14] In the case of biofuels, those from abroad will often be cheaper and have lower life-cycle emissions.

uncertainties, some comparison of current alternative fuel costs relative to petrol and diesel gives a useful indication of the most promising types and the scale of the challenge in expanding demand for these fuels:

- **biofuels** are generally more expensive than petrol and diesel using current technologies. Biofuel sourced from developing or emerging economies can be significantly cheaper than fuels from the UK and Europe because of lower labour costs and better climates for feedstock growth. For example, Brazilian bioethanol can be produced for less than the market price of petrol;
- the cost of **electricity** as a car fuel is difficult to judge because of the absense of comparable vehicles and the wide range of electricity generation costs. However, it is likely that, under many future scenarios, using electricity to power a car would be cheaper than petrol and diesel (especially if cars are charged overnight when electricity demand is lower and there is spare capacity).
- at present, **hydrogen** from low-CO_2 production routes is significantly more expensive than petrol and diesel on a per-kilometre basis[15].

CO_2 abatement costs of fuels

3.36 Putting together information on life-cycle emissions of fuels and their cost allows the cost-effectiveness of fuels in reducing CO_2 to be calculated. Abatement costs are calculated relative to petrol and diesel and are consequently sensitive to oil prices. The following provides an illustration of the current CO_2 abatement costs of a selection of fuels:

- **ethanol** produced in Europe from sugar beet or wheat commonly has a CO_2 abatement cost of between £100 to £150 per tonne of CO_2[15]. Bioethanol from Brazil is often produced more cheaply than petrol and therefore it can be cost-saving;
- **biodiesel** produced in Europe from oil seed rape commonly has an abatement cost of £90 to £150 per tonne CO_2[15];
- CO_2 abatement through use of **electricity** could be cost-saving as electricity can be both lower cost and have lower LCEs than petrol and diesel; and
- the cost-effectiveness of **hydrogen** varies widely depending on the production route. The most cost-effective current routes are from nuclear or wind electricity and wood gasification, with abatement costs ranging from £250 to £450 per tonne CO_2[15].

3.37 With the possible exception of electricity, these abatement costs are relatively high compared to other options for cutting CO_2 in both road transport and the wider economy. For example, as Chapters 4 and 5 discuss, efficiencies from enhanced vehicles and smart driving can be cost-saving. In the future, improved technology and changes to oil prices relative to other energy sources could make transport fuels a much more cost effective area from which to save carbon. The next section discusses the relationship between reducing CO_2 from fuels and other sectors.

[15] *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context*, CONCAWE/EUCAR/ECJEC, 2007.

3.38 This section has discussed the life-cycle CO_2 emissions of different fuels and includes two important insights:

- the life-cycle emissions of fuels are highly dependent on how those fuels are produced; and
- as countries move towards alternative fuels with lower CO_2 emissions over their life cycle, upstream emissions will become increasingly important relative to tailpipe emissions.

TRANSPORT FUELS AND COMPETING USES OF LOW CARBON ENERGY

3.39 When looking at opportunities to reduce CO_2 emissions from fuels, it is important to understand the linkages with other sectors. In particular, road transport must compete for scarce primary energy sources with other sectors, including power generation, heat, aviation, marine transport, and food consumption (in the case of biomass). Any use of low-carbon energy resources, such as biomass, wind, solar and nuclear, for transport reduces the availability of those resources for other applications. The challenge is therefore to ensure that low-carbon energy sources are put to the most efficient and effective use, ensuring that the costs of reducing CO_2 are minimised across the economy. In future, cross-sectoral emissions trading may facilitate such allocations, both within and between countries.

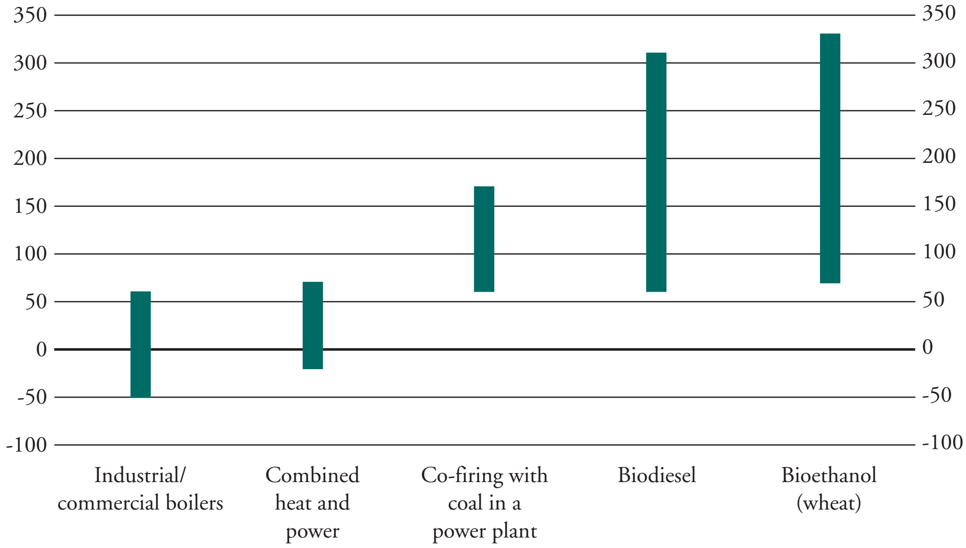
Making best use of biomass

3.40 Biomass is a particularly challenging area, with car transport competing for its use with the power, heat, food, clothing, cosmetics and, potentially, aviation sectors. The UK Government's Biomass Strategy[16] showed that car transport is currently one of the least cost-effective uses of biomass in saving CO_2 (see Chart 3.3). In general, using biomass for heat and power saves CO_2 more cost-effectively. This suggests that, in order to have the largest and most cost-effective impact on CO_2 emissions, biomass should not be used extensively for transport fuels until either potential savings from these other sectors have been exhausted, or until the marginal cost-effectiveness in road transport is greater than in other sectors.

3.41 Nevertheless, some current use of biofuels for road transport is important, to enable technological advances to be made and cost to come down. In future, as the power sector becomes largely decarbonised, or relative energy prices change, the increased use of biofuels for road transport could be cost-effective.[17] On this basis, there is still a case to provide incentives for the development of biofuels for road transport, but these should not be disproportionate to those given for other uses of biomass such as heat and power.

[16] *UK Biomass Strategy*, DTI/DEFRA, 2007.
[17] *Biofuels for Transport*, Worldwatch instiitute, 2007.

Chart 3.3: Illustrative comparison of CO_2 abatement cost ranges for selected uses of UK biomass (£ per tonne of CO_2 abated)



Source: Adapted from the UK Biomass Strategy 2007 Working Paper 1, Department for Trade and Industry).

Need for low-CO_2 electricity

3.42 The use of electricity for road transport (either to charge batteries or to make hydrogen) is a particular area where competing uses of primary energy sources must be considered carefully. Analysis by E4tech for the Low Carbon Transport Innovation Strategy suggested that a total conversion of the UK car and taxi fleet to electricity would equate to 16 per cent of current electricity demand (if hydrogen were to be produced this would equate to 30% of current electricity demand)[18].

3.43 Currently only 4 per cent of the UK's electricity is produced from renewables, with 18 per cent from nuclear power[19]. Thus, producing additional low-carbon electricity for transport from without displacing those sources of low-carbon electricity that are (or could be) used for meeting existing demand is a major challenge. Shifting from petrol and diesel to electricity is therefore only as CO_2-efficient as the marginal means of generating that electricity. This implies that powering cars by electricity may be particularly attractive for countries with additional scope to produce low-CO_2 electricity (for example, countries such as New Zealand, which generates 70 per cent of its electricity from hydropower[20]), although a future global emissions trading scheme may equalise the incentives for this. The UK is currently taking steps towards cleaner electricity generation – for example, through inclusion of the power sector in the EU Emissions Trading Scheme and through the Renewables Obligation, which targets 10 per cent of electricity from renewable sources by 2010. It is also supporting research into potential future low-carbon technologies such as carbon capture and storage.

Flexibility versus certainty

3.44 The key challenge for road transport and the wider economy is to ensure that there is flexibility to adopt new low-carbon technologies as they emerge and for low-carbon energy sources to be used efficiently across the economy, while at the same time providing the certainty needed for development of low carbon car transport fuel and vehicle technology. This will be an important consideration for Part II of the King Review.

[18] *A Review of the UK Innovation System for Low Carbon Road Transport Technologies,* E4tech, 2007.
[19] *Energy White Paper,* Department for Trade and Industry, 2007.
[20] New Zealand Energy Info

BIOFUELS CAPACITY AND SUSTAINABILITY ISSUES

Background

3.45 Biofuels are currently the subject of much debate in the UK, Europe and internationally, as measures to increase production are implemented around the world. In 2008, the Renewable Transport Fuels Obligation (RTFO) is due to commence in the UK, requiring 5 per cent of all fuel sold on forecourts to come from renewable sources by 2010-2011. In early 2007, the EU agreed on a draft energy plan that includes a binding biofuels target of 10 per cent (by energy content) by 2020. The United States has a target of 28 billion litres of ethanol to be produced by 2012 and Brazil already has 20-25 per cent ethanol in the gasoline mix.

3.46 Biofuel use is currently being promoted because of the potential reduction in CO_2 emissions it offers, as well the security of supply benefits from reduced dependence on crude oil. There are also co-benefits to domestic and foreign farmers from increased demand for biofuel feedstocks.

Current challenges with biofuels

3.47 There are a number of potential drawbacks associated with the use of biofuels, including increased pressures to convert land to agriculture, increased upward pressure on food and land prices and other negative effects from agricultural expansion, such as increased water use.

Impacts of land-use change

3.48 Increased demand for biofuel feedstocks is likely to increase significantly pressure to convert land to agriculture. The impacts of biofuels on land-use can either be direct – if land is converted specifically to grow biofuel feedstocks – or indirect – if biofuel feedstocks are grown on existing agricultural land, displacing the incumbent agricultural use onto other land.

3.49 Conversion of land can have major costs, depending on the previous use for the land. Many current land uses have enormous environmental value. Forests and grasslands "lock-up" large amounts of CO_2 in their plants and soil and this is released if they are converted to other uses. It is estimated that if forested land is cleared, two to nines times more CO_2 is released than would be saved by using an equivalent area of land to grow biofuels for 30 years[21]. Put another way, to pay back the initial release of CO_2 from clearing the forest would take 60 to 270 years of growing biofuels (using current technologies). The loss of natural forests around the world contributes more to emissions than the global transport sector[22] and therefore it is important to ensure that increased biofuel demand does not exacerbate this problem. There are also many other environmental benefits provided by forest cover, such as flood risk mitigation. In some areas, there can be a loss of biodiversity if habitat is destroyed (this can be very severe if biodiversity-rich rainforest land is cleared). None of these benefits is adequately priced into the market and therefore rapid expansion of biofuel demand would put increasing pressures on land use and risk exacerbating the effects of these market failures.

Potential disruption to food markets

3.50 Expanding biofuel demand could also increase upward pressure on global food and land prices that could drive inequality in developing countries. Food prices are very sensitive to changes in supply. To the extent that biofuel compete with food for arable land, there is therefore a risk of significant food price rises associated with increased biofuel production. This is mainly a concern for the urban poor in developing countries, who spend a high proportion of their income on food, and for poor countries that are net importers of food.

[21] *Carbon mitigation by biofuels or by saving and restoring forests,* Righelato and Spracklen, 2007.

[22] *Stern Review on the Economics of Climate Change*, 2006.

Current land requirements of biofuels

3.51 Currently, biofuels tend to require a large amount of agricultural land relative to the volume of fuel that can be produced. Land requirements vary significantly depending on factors such as the feedstock, climate, amount of fertiliser used and production technology. Despite these uncertainties, various studies provide a useful illustration of the scale of the current requirement and the likely immediate capacity of biofuel production. For example:

- approximately 1 per cent of the world's available arable land currently supplies 1 per cent of global transportation fuels, along with by-products;[23] and
- if all set-aside land and all exports in the EU were diverted to biofuels, a maximum of 4 per cent of conventional road fuels could be substituted. 27 per cent of projected EU cereals production in 2012 would be needed to meet the 5.75 per cent petrol/diesel replacement target.[15]

3.52 These estimates suggest that, with current technology and yields, biofuel production to supply more than 5-10 per cent of transportation fuels would risk seriously impinging on food supply and/or major land-use changes. As discussed later, future biofuel technology has the potential to reduce land requirements of biofuel crops substantially, although they are still likely to be subject to major land constraints.

Other pressures on land use and food prices

3.53 Any expansion of biofuels must also be considered carefully in the context of other major pressures on land use, food prices, and water including:

- **rising global population and incomes,** leading to increased demand for food and other biomass-derived products (such as paper and cosmetics). The United Nations estimates that the world population will grow to around 9 billion in 2050, up from 6.5 billion in 2006;
- **changing global diet** towards meat and dairy products, which require large inputs of grain for animal feed;
- **the consequences of climate change,** reducing yields and increasing droughts in some regions reducing potential supply; and
- increased use of **biomass for heat and power**.

3.54 Some of these effects could be offset by increases in yields resulting from improved farming technology and increased investment (especially in developing countries, where yields can be just a tenth of those on comparable land in developed countries[24]). However, pressures on food prices and land use are likely to increase over time and even moderate expansion of biofuels production could have impacts in this context. Any UK and European targets also need to be considered carefully in relation to other countries' policies on biofuels, to ensure that global demand can be delivered sustainably.

3.55 Expanding biofuels production could also have other negative environmental effects, including on water supply. Globally, the agricultural sector accounts for 70 per cent of freshwater use (and this can be as much 90 per cent in developing countries). The processing of biofuels can also require large amounts of water. Thus any expansion of agriculture for biofuels could have significant effects on water availability, particularly in areas where there are already shortages. Other effects from expanding biofuels include possible damage to water and soil from the use of pesticides and fertiliser.

[23] *World Energy Outlook 2006*, International Energy Agency.
[24] *Biofuels for Transport,* Worldwatch Institute, 2006.

Reducing land requirements is critical

3.56 Given these pressures, developing and using biofuels that have lower land, water and fertiliser requirements, and which do not compete directly with food, is essential if the industry is going to expand in a sustainable way. Without these developments, expanding biofuels production could prove to be unsustainable in both environmental and economic terms. CO_2 savings per unit of land is an important criterion by which biofuels should be judged, alongside savings per vehicle kilometre.

Biofuels in the future

3.57 Biofuels from lignocellulosic feedstocks[25] have significant potential to lower land requirements and impacts on food markets. They make use of the non-food parts of crops (agricultural residues) and high yielding non-food crops (such as switchgrass and poplar) and crops that can be grown on marginal land (e.g. jatropha). These crops can often grow without the need for irrigation, reducing pressures on water supply.

3.58 Improvements to yields through plant breeding, possibly accelerated through genetic modification, could also make a major difference to sustainable capacity. In addition, a significant amount of biofuel could, potentially, be produced from feedstocks without land requirements (for example, agricultural and municipal waste[26] or even ocean algae). These developments would be expected to reduce the life-cycle CO_2 emissions of biofuels significantly.

3.59 However, making these options cost-effective is a major challenge. In particular, the low energy density of lignocellulosic feedstocks means that transporting them to centralised processing plants (which exploit economies of scale) is costly. If challenges such as these can be met, the global production capacity of biofuels will increase significantly.

Expanding biofuels at the right pace

3.61 There is uncertainty over when these improved biofuel technologies can be delivered cost-effectively. Biofuels production should not be expanded ahead of the development of these technologies as this risks major changes in land use and increases in food prices, as well the potential of "lock-in" of early biofuel technology at the expense of better future technology. At the same time, development of improved biofuels will require large investments over long time horizons. Such investment will only be forthcoming if there is long-term confidence over future demand. Providing sufficient market deployment of biofuels to encourage improvements in biofuels without causing adverse environmental and social impacts is a major challenge.

Providing international safeguards

3.62 The Renewable Transport Fuels Obligation, which requires 5 per cent of all fuel sold to come from renewable sources by 2010-2011, will be a major step in developing the biofuels industry. There are two key aspects to ensuring this is successful. First, as discussed above, demand for biofuels should not be expanded beyond 5 per cent ahead of technological developments to reduce their environmental and social impacts. Second, strong safeguards need to be in place to ensure that the 5 per cent requirement is delivered sustainably and with maximum benefit. There are a number of aspects to this, including:

- limiting direct impacts on land use (particularly avoiding conversion of land with high carbon stocks and/or biodiversity value);
- limiting impacts on water supply;

[25] Lignocellulosic feedstocks include woody materials, grasses, and agricultural and forestry residues, which contain cellulose, hemicellulose and lignin. They can be broken down in a number of ways to be used as biofuels[17].

[26] The National Society for Clean Air estimates that UK supplies of waste could be sufficient to supply 16 per cent of transport fuel (probably as biogas).

- limiting damage to soil and water resources from use of fertiliser and pesticides; and
- encouraging biofuels with the lowest life-cycle CO_2 emissions.

3.62 As a first step, many countries, including the UK, are working towards certification schemes to help meet the above challenges. International agreement on these will make them more effective. Full safeguards need to be agreed and enforced at a global level and, until these are in place and proven, caution is needed.

3.63 It is unlikely to be possible to address the indirect land-use impacts of biofuels through certification schemes and, as the Stern Review emphasised, international agreement will be needed on a system to protect environmentally valuable land such as forests and grasslands.

FUTURE PATHWAYS

A mixture of fuels is likely

3.64 This section discusses what the future UK fuel mix might look like if good policies are in place to reduce CO_2 from fuels. Forecasting the future of fuels is very difficult due to major uncertainties around rates of technological development and energy prices. This serves to highlight the importance of allowing flexibility for the market to respond to changing circumstances. However, as a general statement, it is likely that by 2030 a range of different fuels will be represented at significant levels in the fuel mix.

Liquid fuels will still be needed in the foreseeable future

3.65 Currently the vast majority of vehicles operate on liquid fuels (petrol and diesel with the possibility of some blending with liquid biofuels). As Chapter 4 discusses, fully electric or fully hydrogen-powered cars are still a long way from achieving significant market penetration and the most likely major change to the car fleet over the next 25 years will be through improvements to existing engines and use of hybrid vehicles, which are still likely to require significant amounts of liquid fuel.

Biofuels capacity is limited

3.66 Given that the liquid fuel requirement is likely to remain high, biofuels offer the greatest potential to reduce CO_2 from fuels over the next decade. However, even allowing for advances in biofuel technology, they are unlikely to represent the dominant part of the fuel mix as a result of land and other constraints. Therefore, use of conventional petrol and diesel is expected in 2030 and beyond.

3.67 There are three further reasons why a mixture of fuels is likely in 2030:

- different fuels suit different uses. For example, fully electric cars are better suited to short city journeys due to their limited range and recharging times, and larger vehicles can accomodate larger tanks, as required for gaseous fuels such as hydrogen and biogas;
- niche availability of energy sources will make some fuels better suited to certain localities. For example, at times and places where there is a surplus of renewable energy (e.g. hydro or wind power) it might be most cost-effective to convert this into hydrogen for road transport uses; and
- biofuels will often give better performance when blended with petrol.

The importance of clean electricity generation

3.68 A key implication of the above is that, assuming biofuels do not become the dominant part of the fuel mix, electricity (either to charge batteries or to produce hydrogen) is likely to play a major role if car transport is to be largely de-carbonised. Ensuring this extra electricity demand is produced from low-CO_2 sources will require electricity generation to be largely decarbonised.

OPPORTUNITIES FOR UK BUSINESS AND THE RESEARCH AGENDA

3.70 A switch towards alternative fuels offers opportunities for UK business. In particular, the UK has a strong capability in plant science and could therefore play a leading role in development of biofuel crops with high yields and low land requirements.

Research agenda

3.71 The research agenda should be focused on overcoming key obstacles to alternative fuels use, including (but not limited to):

- developing batteries with longer ranges and faster recharging;
- developing cheap and low-CO_2 ways of producing, distributing and storing hydrogen;
- improving crop yields to reduce the land requirements of biofuels, through either plant breeding or genetic engineering; and
- improving technology for converting biomass (in particular non-food biomass) into fuel.

3.72 Breakthroughs in any or all of these areas would make a major difference in reducing CO_2 from road transport fuels.

CONCLUSIONS

3.73 Petrol and diesel are highly efficient and convenient ways to provide energy for road transport. The task of replacing them with low-CO_2 alternatives is therefore challenging. The life-cycle CO_2 emissions of alternative fuels (as well as petrol and diesel) are highly sensitive to how they are produced.

3.74 Demand for biofuels should not be expanded too quickly, before technological developments to improve their wider environmental and social impacts have been made. Strong international action is needed to ensure that currently planned biofuels targets are met sustainably. In future, technology has the potential to reduce land requirements of biofuels substantially, and they could therefore play an important role in reducing CO_2 from road transport fuels.

3.75 Achieving low-carbon electricity generation is essential to a long-term goal of decarbonising road transport. This will create extra demand for electricity and ensuring this is supplied from low-CO_2 will require further significant progress towards carbon-free electricity generation. This will be a major challenge, especially in the light of long planning and commissioning timescales for power plants.

4 Vehicle technologies

KEY MESSAGES

4.1 Technologies with the potential to reduce CO_2 emissions per kilometre from the average new car by up to 30 per cent are already close to mass market. Some of these technologies are already being built into the most efficient models manufacturers offer. By increasing fuel efficiency, many of these technologies can be cost-effective for consumers, achieving reductions in CO_2 emissions at a cost saving over the life of the car. However, there are a number of barriers to the large-scale deployment of these technologies in cars.

4.2 Cars that emit 50 per cent less CO_2 than today's equivalent models could be widely available by 2030. Achieving this will probably involve the use of battery-electric and hybrid technologies, and possibly lightweight materials. This will require advances in technology, particularly in respect of batteries, in parallel with cost reduction.

4.3 Beyond 2030, reductions in carbon emissions to almost zero on a well-to-wheel basis could be achieved using battery-electric or hydrogen-electric propulsion systems, if sufficient low- or zero-carbon electricity is available. Significant technical and cost challenges must be overcome before these can become commercial.

4.4 It is important that the UK capitalises and builds on its strengths. The UK's advanced technology firms are leading innovation in key areas – specialist firms are already demonstrating electric vehicle and hydrogen fuel cell technology, and are working with the vehicle manufacturers to reduce costs.

4.5 The UK has a short-to-medium term interest in the production of low carbon internal combustion engines, and has world-class capabilities in advanced automotive engineering. The UK produces 3 million internal combustion engines every year. As the technology moves on rapidly, there are major opportunities for the UK, if manufacturing capability can keep pace with new demands.

INTRODUCTION

4.6 This chapter focuses on the role of vehicle technology development in reducing the CO_2 emissions of cars. As noted in Chapter 2, vehicle efficiency is a key determinant of how much CO_2 is released into the atmosphere within a well-to-wheel framework. Vehicle efficiency refers to how efficiently a vehicle converts the energy contained in a fuel into motion of the vehicle. There are many factors that affect this, including the efficiency of the engine or propulsion system, the weight of the car and its aerodynamics.

4.7 The technologies discussed in this chapter have the potential to increase vehicle efficiency. Significant further improvement of existing petrol and diesel engine types is possible in the short-to-medium term. Technologies to reduce vehicle weight and hence vehicle emissions are also addressed.

4.8 The longer-term possibilities of propulsion systems using alternative forms of energy such as batteries or hydrogen are considered in this chapter, and a brief analysis of the development requirements for these technologies outlined.

4.9 The chapter concludes with a discussion of the path to market for the new technologies to reduce CO_2 emissions, and possible roles for the UK in the development of low-carbon vehicles.

PREVIOUS VEHICLE TECHNOLOGY DEVELOPMENTS

4.10 The first mass-produced motor vehicle was the Ford Model T, launched in 1908. This development started the trend of falling production costs, which, with rising incomes, has allowed mass ownership of cars powered by internal combustion engines to develop across the world.

4.11 Over the last century, cars have improved continuously in terms of performance, comfort, style, safety and economy. In particular, the last three decades have seen cars develop that are more reliable, perform better and incorporate more safety and convenience features, such as airbags and air conditioning. Meanwhile, cars have become more affordable to buy and run, leading to rapid growth in car ownership in many countries, including the United Kingdom. New car registrations today amount to 2.3 million per annum in the UK.[1]

Trends in CO_2 emissions

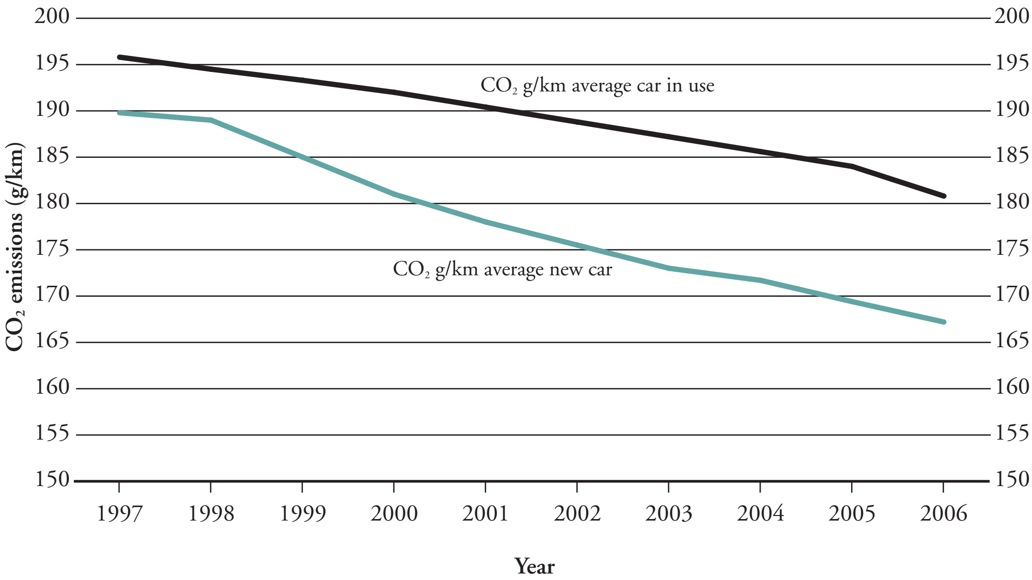
Cars have improved in many ways, including environmental performance

4.12 Car manufacturers have gradually brought models with improved fuel economy to market, with innovation being most rapid at times of rising and high and rising oil prices or unstable oil supply. Historically, environmental performance improvements in Europe have largely been a by-product of this pursuit of greater fuel efficiency and economy. However, since the early 1990s, legislative and regulatory approaches have played a role in pulling through new technological development. Emissions regulations – with a specific focus on environmental objectives – made installation of catalytic converters and fuel injection on vehicles a requirement. Since these regulations, catalytic converters have been commercially deployed in nearly all cars in Europe. This has reduced harmful emissions from cars – for example, emissions of oxides of nitrogen from cars in the United Kingdom fell by 45 per cent between 1990 and 2005[2].

4.13 More recently, as the impact of CO_2 emissions on climate change has become clearer, the amount of CO_2 emitted by cars has become the subject of increased policy focus. In 1998, European motor manufacturers entered a voluntary agreement to reduce CO_2 emissions by 25 per cent by 2008/9 – to 140g per kilometre for the average car sold. Members of the Japanese and Korean trade associations joined this voluntary agreement in 1999[1]. Chart 4.1 shows that the CO_2 emitted by the average new car sold in the UK, as measured on the European combined drive cycle (the standard approach to measuring car fuel economy and CO_2), has fallen by 12 per cent since 1997, from just under 190g/km to 167g/km. The reduced emissions of new cars is slowly feeding through into the wider fleet in use – average CO_2 emissions per car have fallen by around 8 per cent, from 196g/km in 1997 to 181g/km in 2006[1].

[1] *SMMT Annual CO_2 Report - 2006 Market*, The Society of Motor Manufacturers and Traders Ltd, 2007.
[2] *e-Digest Statistics About: Air Quality*, Department for Environment, Food and Rural Affairs, 2006.

Chart 4.1: Tailpipe CO_2 emissions from average new cars and cars in use in the UK



Source: SMMT (2007).

4.14 The fall in average emissions of new cars has occurred despite a trend towards increased sales of larger and more powerful vehicles. This reflects the fact that most cars being sold in the UK now emit significantly less than the equivalent model sold ten years ago.

Cars have become more efficient

4.15 Recent improvements in engine technology such as direct fuel injection have helped to achieve increased fuel economy and reductions in CO_2 without sacrificing performance, cost or convenience to the car buyer. Despite a 20 per cent weight gain of midsize vehicles in the past 20 years, a long-term trend of 0.6 per cent fuel efficiency improvement per year has been observed[3], as a result of technical improvements. In addition, as the performance of diesel engines has improved, many buyers have switched from petrol to diesel vehicles. UK market penetration of diesel cars has more than doubled since 1997 to 38 per cent in 2006[4].

4.16 However, some recent trends and requirements in vehicle design have worked against the objective of reducing CO_2 emissions. Additional weight and less efficient aerodynamics, arising for example from requirements for improved safety and to reduce NO_X emissions, have offset some of the increase in vehicle efficiency that could otherwise be achieved. Consumer preference for increases in engine size, power and additional electrical equipment has further increased the weight of vehicles, slowing progress in reducing CO_2 emissions.

CO_2 emissions per car are falling but faster progress is needed

4.17 Chart 4.1 clearly shows that significant progress has been made. However, there are signs that these positive trends are slowing. At the current rate of progress, car manufacturers as a group are unlikely to meet the European voluntary target of 140g/km by 2008/9. In 2006 the average new car sold in Europe emitted 160g/km[5].

[3] *'Carbon to Hydrogen' Roadmaps for passenger cars – Update,* Ricardo, 2003.
[4] *SMMT Annual CO_2 Report - 2006 Market*, The Society of Motor Manufacturers and Traders Ltd, 2007.
[5] *Car industry progress on climate grinds to a halt,* European Federation for Transport and Environment, 2007.

4.18 Over the next 25 years, to see continued substantial reductions in the CO_2 emissions of the average car, technology must be brought to market more quickly than current trends imply. The following section discusses how further progress might be made through new technological developments.

Future technology options

4.19 A range of technology options has the potential to improve the environmental performance of cars in the future. This includes evolutionary improvements to current engines, new powertrain[6] technologies and use of lightweight materials.

4.20 New technologies will only succeed commercially if consumer expectations of range, comfort, safety and speed continue to be met. The following sections assess (for the short, medium and long term) the most promising vehicle technologies, in terms of the contribution they could make to reducing car CO_2 emissions. The sections discuss how close to market these different technologies are, and the likely timescales for their introduction, given the challenges in bringing new technology to market.

SHORT-TERM TECHNOLOGY OPTIONS BASED ON CONVENTIONAL SYSTEMS

Incremental technological change is currently most cost-effective

4.21 Currently the most cost-effective way to secure further reductions in vehicle CO_2 per car is to continue increasing the efficiency of the conventional internal combustion engine. Internal combustion engines offer the advantages that, with the benefits of 100 years of cost reduction, they are relatively inexpensive to produce and they perform reliably under a range of motoring conditions. They use liquid fuels such as petrol and diesel, which, as Chapter 3 discussed, are energy-dense, and the infrastructure for distribution and storage is highly developed in many countries.

4.22 However, internal combustion engines are relatively inefficient at converting the energy in petrol and diesel into forward motion, particularly when a car is being driven in slow urban traffic. Internal combustion engines are also relatively noisy in comparison with electric motors and produce other harmful emissions such as nitrous oxides and particulates. Despite their environmental disadvantages, the economics of producing vehicles powered by internal combustion engines remain strong. Vehicle manufacturers have invested heavily in the latest generation of internal combustion engines and they will be keen to secure a good return on these investments before bringing alternative technologies to market.

Incremental powertrain efficiency enhancements

4.23 Over the next few years, incremental technological improvements to the internal combustion engine and other elements of the powertrain hold the prospect of significantly improved environmental performance. As Box 4.1 illustrates, a range of innovations, including variable valve actuation, direct injection and turbo-charging, as well as “mild” hybrid technologies such as stop-start and regenerative braking, all offer potential for improved vehicle efficiency.

[6] The powertrain describes the components that generate power and convert it into motion. It includes the engine, transmission and driveshafts.

Box 4.1: Incremental improvements to conventional powertrain technologies

Some technologies that are being explored for the next car model cycle, and in a limited number of cases are being introduced in this model cycle are:

- stop-start – this cuts engine power when the car is at a standstill, and starts up the engine when the driver places the car in gear to pull away;
- direct injection – this ensures that the fuel is burnt more efficiently;
- variable valve actuation – this optimises the way in which fuel enters the combustion chamber of the engine;
- boosting (turbo/supercharging) – these technologies pressurise air in the fuel mixture to increase power. This means that the same power can be achieved with a smaller engine;
- down-sizing – the technologies above mean that similar performance can be achieved with a smaller engine (for example, 1.2 litre instead of 1.6 litre), reducing weight and using less fuel;
- regenerative braking – this captures the energy otherwise lost as friction when a car slows down, in electrical form; and
- electrical motor assistance – an electric motor provides assistance to the internal combustion engine, reducing the amount of petrol or diesel used.

4.24 Many of these technologies offer significant CO_2 and fuel efficiency savings. A number of these can also be delivered at relatively low cost, if they can be rolled out on a sufficiently large scale. Table 4.1 provides an indication of the benefit to a typical current petrol engine by adding the measures individually. With each additional measure the incremental effect is proportionately less, and it is not envisaged that all would be adopted in a single vehicle. However, allowing for this, and taking a selection of the most cost-effective technologies, CO_2 reductions of up to 30 per cent are potentially achievable. These are all evolutionary changes and technically it should be possible to deliver this level of benefit in new models, in a 5-10 year timescale.

Table 4.1: New engine and transmission efficiency savings, and indicative production costs

Technology	Efficiency saving	Cost per vehicle (£)
Direct injection and lean burn	10 – 13 %	200 – 400
Variable valve actuation	5 – 7%	175 – 250
Downsizing engine capacity with turbocharging or supercharging	10 – 15%	150 – 300
Dual clutch transmission	4 – 5%	400 – 600
Stop–start	3 – 4% *	100 – 200
Stop–start with regenerative braking	7%*	350 – 450
Electric motor assist	7%*	1,000
Reduced mechanical friction components	3 – 5%	Negligible

** Figure quoted is for the whole drive cycle. Savings are much greater in urban driving conditions.*

Ranges derived from a number of sources, including the International Energy Agency (IEA), Institute of European Environmental Policy (IEEP), California Air Resources Board (CARB), Ricardo. Cost estimates derived using approximate conversion to Sterling.

Non-propulsion technologies

4.25 In addition, there is some scope to use non-propulsion technologies, including weight-saving materials, improved aerodynamics and lower rolling resistance tyres, to improve vehicle efficiency. Weight savings reduce the energy needed to accelerate the car, and improved aerodynamics and reduced rolling resistance help reduce the amount of energy needed to maintain speed. This reduces fuel consumption, and enables a car to be manufactured with a less powerful and possibly lighter engine. The second and third round effects of weight reduction enable the initial gains of lightweighting to be built on.

4.26 Table 4.2 sets out the approximate range of efficiency benefits that can be achieved through lightweighting, improved aerodynamics and reduced rolling resistance, and indicative costs per vehicle based on mass production.

Table 4.2: Non-propulsion technologies, efficiency savings and indicative production costs

Technology	Efficiency saving	Cost per vehicle (£)
Lightweighting	10%	250 – 500
Low rolling resistance tyres	2 – 4%	50 – 100
Improved aerodynamics	2 – 4%	–

Source: IEA (2007). Cost estimates derived using approximate conversion to Sterling.

Overall potential of short-term technology options

30% efficiency savings are achievable for new cars

4.27 The discussion of potential propulsion and non-propulsion technologies above shows that there is significant potential to reduce CO_2 from new vehicles over the next 5-10 years. Different technologies will suit different vehicles but, in general, by adopting a small selection of the most cost-effective technologies, 30 per cent efficiency savings could be achieved for the average new vehicle, relative to today's equivalent model. The additional production cost could be around £1,000 to £1,500 per vehicle – as long as vehicles incorporating these technologies could be produced, and sold, on a sufficiently large scale. The other caution is that these savings are not eliminated, at least in part, by additional weight or power consumption, as a result of additional equipment and features in the vehicle.

These technologies can be cost-effective

4.28 If delivered at these prices, many of these technologies can be cost-effective for the consumer. A 30 per cent efficiency saving would lead to petrol costs being reduced by between 3 and 5 pence per mile depending on the size of car[7]. If 30 per cent efficiency savings could be achieved, someone who buys a car that has these technologies and drives 10,000 miles a year would typically lower their fuel bill by between £300 and £500 a year (compared with a car of average efficiency for its class that can be bought today). In this case, the initial investment could be recouped in as little as 3-5 years. The payback time would be shorter still for high mileage drivers, or drivers that choose technology particularly suited to their journeys (for example, stop-start for urban driving). For most drivers the additional cost would be paid back over the lifetime of the car.

4.29 The short-term challenge is to get cars with these benefits into showrooms and onto the road as quickly as possible. The sooner these technologies can be brought into production, the faster CO_2 emissions from new cars, and ultimately from the fleet of cars on the road, will fall.

[7] Assuming the petrol costs range between 9.41p and 15.81p per mile for most cars; *(Source: Petrol car running costs – basic guide for 2007,* The AA, 2007).

4.30 Manufacturers are only likely to introduce more efficient vehicle technologies if they are confident that it is profitable to do so. Given the scale of the industry, investment decisions that directly affect the UK car market are usually taken on a European scale. Most investment in new models occurs several years before the model is introduced to the consumer, and the decision to add new and expensive technology to a car is risky.

Major barriers to realising benefits

4.31 There are potentially strong barriers preventing these technologies from become widely available and adopted by consumers as quickly as might be technologically possible and cost-effective:

- consumers tend to discount heavily the potential fuel savings from more efficient vehicles;
- fixed costs can delay roll-out of new technologies; and
- manufacturers cannot realise economies of scale if demand is weak.

Weak consumer demand for low-CO_2 models

4.32 The current evidence, as discussed in Chapter 5, suggests that many UK buyers discount heavily, and some do not consider, vehicle efficiency benefits at the point of purchasing a car. They are therefore less inclined to adopt efficient vehicles than the financial incentive from fuel economy savings might suggest. In addition, the majority of buyers tend to rate the environmental impact of vehicles relatively low in their purchase criteria. It has taken a long time for consumers internationally to adopt environmentally focused models in large numbers, particularly those using the most advanced technology, such as hybrids. Often models have had to be adapted and re-marketed to fall in line with customer tastes. Some models that were brought to market at too high a cost premium or too early failed commercially and were abandoned by their manufacturers.

Fixed costs and scale issues

4.33 The large fixed investment required to introduce new technologies can discourage manufacturers from deploying new technologies even if they may be more cost-effective in the long term. This is because manufacturers have already made significant investments in the production of their existing vehicles, and therefore continuing to produce these is cheaper, more profitable and less risky in the short term.

4.34 Furthermore, the cost of new technologies tends to fall rapidly as production increases, due to dynamic increasing returns from economies of scale and learning effects. Evidence demonstrates the existence of experience curves for car manufacturing, with the cost of new technologies falling over time. For example, the price of the Model T Ford fell by more than two-thirds in its first ten years of production. In the absence of sufficient demand, these scale benefits cannot readily be realised.

4.35 Both the demand and supply side of the car market have tended to be more disposed towards the production and consumption of ever more powerful cars than cars that are as efficient as they could be. Manufacturers have found that offering higher performance in their cars makes them more competitive – it is also generally cheaper to increase the performance of a car than to increase its fuel efficiency. Selling higher performance is therefore currently more profitable and less risky in a competitive, global industry where profit margins are tight. There are, however, some signs that vehicle manufacturers are prepared to bring greater numbers of low-CO_2 models to market. Many of the major manufacturers have recently introduced low-carbon variants of mass-market models to their ranges. A key challenge is to accelerate this progress and ensure potential CO_2 savings are realised.

Vehicles and fuels

4.36 Emissions of CO_2 from the average car in the fleet could be reduced if more buyers opted for diesel-powered cars. Diesel engines are inherently more efficient than petrol engines, with equivalent diesel engines using around 25 per cent less fuel under almost any driving style[8]. The UK has a lower proportion of diesel vehicles than Europe, but that proportion is growing rapidly – diesel cars represented 38 per cent of new car sales in 2006[9], more than double the proportion in 1997.

4.37 It is not clear that the proportion of drivers that opt for diesel will continue to grow at this rate. The efficiency gap between petrol and diesel engines is likely to narrow over time, and scope for further efficiency increases of diesel engines may be as low as 5-10 per cent. Diesel engines typically cost twice as much to manufacture as today's petrol engines and the additional cost of manufacturing diesel engines that are compliant with Euro V and VI regulations is uncertain.

4.38 The vehicle modification costs associated with using biofuels are relatively low. Most vehicles could already run on fuels that are 10 per cent biofuel, and models that can run on 85 per cent blend bioethanol (E85) are slowly being introduced in the UK.

THE MEDIUM TERM OUTLOOK – BEYOND THE INTERNAL COMBUSTION ENGINE AND TOWARDS ELECTRIC PROPULSION

4.39 There are limits to decarbonisation through developments of conventional petrol and diesel engines. In the medium term, particularly between 2015 and 2030, further efficiency gains are likely to come increasingly from the use of electric hybrid propulsion systems.

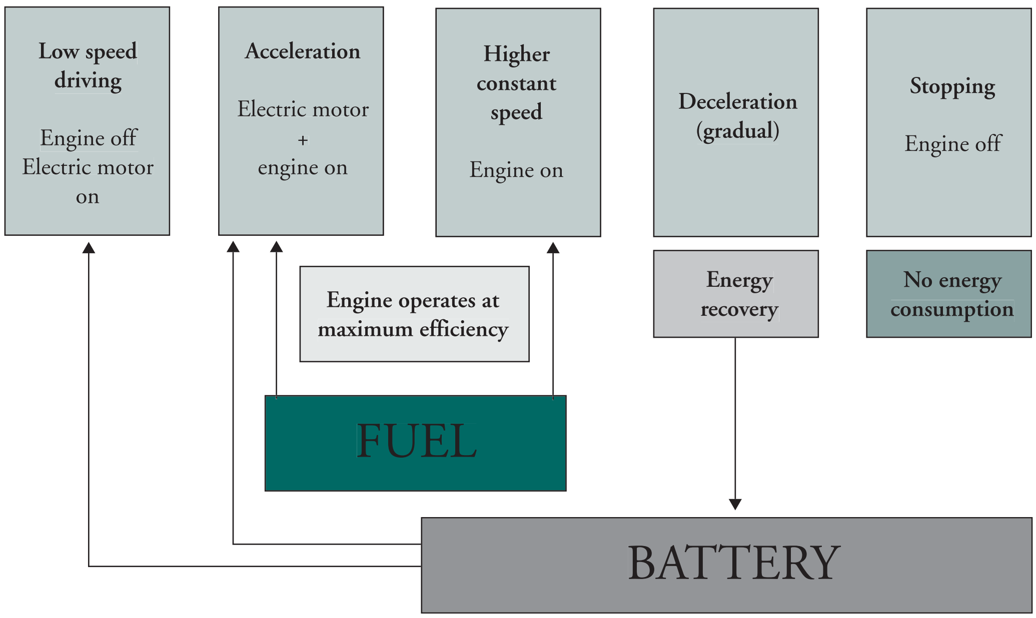
4.40 A full electric hybrid system combines a battery to store energy, and an electric motor to deliver power to the wheels, with another power source such as an internal combustion engine. A few full hybrid car models are already available. In all vehicles currently being marketed as "hybrids", the two power sources in the system are a petrol internal combustion engine and electrical power from a battery, charged by the engine. The car can be driven for a limited distance (typically 2 kilometres or less), at lower speeds, running on the battery alone. The internal combustion engine is used at higher speeds, and electronics ensure that the engine is run closer to its optimum efficiency than in a conventional car.

Hybrid technologies can enhance efficiency

4.41 Hybrid technology allows the internal combustion engine to be run close to its optimum efficiency point, with stored electrical energy used to power the car when it is being driven at lower speeds and under low loads, switching to power from the internal combustion engine at higher speeds and under hard acceleration. Hybrid technology also allows the internal combustion engine to be downsized, delivering a weight saving, which can partly offset the additional weight of a battery and electric motor. Efficiency improvements from current hybrid technology can deliver up to 35 per cent fuel savings, depending on where and how the car is driven. The greatest efficiency gains compared with a conventional car are made in town driving with frequent acceleration, braking and stops. Diagram 4.1 illustrates how hybrids can save fuel and reduce CO_2. With current battery technology, the amount of energy that can be stored in the batteries is limited. As a result, hybrids currently show little or no gain in efficiency, relative to a conventional car, on out of town journeys at higher and steady speeds. However, other regulated emissions are much lower than today's typical diesel.

[8] Ricardo presentation.
[9] *SMMT Annual CO_2 Report - 2006 Market,* The Society of Motor Manufacturers and Traders Ltd, 2007.

Diagram 4.1: How hybrids can save fuel and reduce CO_2 emissions



4.42 Table 4.3 shows that current full hybrid vehicles are relatively expensive to produce (up to £4,000 more than a petrol car for a state-of-the-art full hybrid equivalent). As a result, current hybrid models are priced at a premium over conventionally powered equivalents. However, some environmentally-conscious consumers, and those buying at premium end of the market, are willing to pay for this technology. The number of hybrids on UK roads is growing rapidly: in the first half of 2007, the number of hybrid vehicles registered in the UK rose from just over 3,000 to more than 6,500, although this remains a very small proportion of UK vehicles.

Table 4.3: Hybrid technologies

Hybrid type	Achievable increase in vehicle efficiency	Production cost increase per vehicle	State of technology readiness
Mild	20% – 35%	£1,000 – £1,500	Ready to market. Current models in the market offer full hybrid capabilities
Full	25% – 50%	£2,000 – £4,000	Early examples in the market today: Toyota Prius, Honda Civic, Lexus models
Plug-in	Possibly greater than 50%	£6,500 for 35km electric range £20,000 for 350km electric range	Technology being developed

Sources: Ricardo, IEEP.

Scope for reduction in cost

4.43 Hybrid technology is not currently a cost-effective solution for most drivers, but there is considerable future scope for reduced production costs, as manufacturing volumes rise, and for improvements in battery technology. The least expensive forms of hybrid technology – mild hybrid technology, which bundles together stop-start, regenerative braking and electric motor assistance – may become available in cars much more widely in the short term at a cost acceptable to many consumers. This could be the start of a pathway where the costs of full hybrids are reduced and they are adopted more widely, although there are differing views in the motor industry on how quickly hybrids that offer a cost-effective option for most consumers will come to market.

Battery challenge for hybrids

4.44 For the greatest CO_2 and efficiency benefits to be gained from hybrid technology, the battery will need to be charged by electricity from the grid rather than the internal combustion engine. These "plug-in" hybrids are vehicles that can be plugged into an external charging point to extend the electric drive range beyond that achievable from charging via the internal combustion engine. This requires greater battery capacity than other hybrids. As Table 4.3 shows, current battery technology does not allow sufficient range at a cost likely to be acceptable to most consumers. For plug-in hybrids to become convenient for most users, batteries must be cheaper, with an energy density at least several times current levels, and charging that takes minutes rather than hours.

4.45 The ongoing development of hybrid technologies, as well as offering CO_2 benefits in its own right, should also support progress on longer-term technologies. The development of battery technologies could, over time, facilitate the ultimate mass adoption of fully electric vehicles. Similarly hybrid electric systems design, electrical and control technologies could allow transition to either battery-electric or hydrogen fuel cell powered vehicles.

LONGER-TERM TECHNOLOGIES

4.46 While hybrids appear to offer the best medium term vehicle option for achieving CO_2 reductions, it is difficult to forecast which technologies will have the greatest role to play in the longer term. As Chapter 3 notes, cars that are fuelled by electrical power or hydrogen will potentially have far lower emissions than cars fuelled by petrol or diesel, when considered on a "well-to-wheel" basis, and these are considered to be the best long-term options. However, in both cases, there are major technological challenges to be met.

Electric vehicles

4.47 Fully electric, battery-powered vehicles – if using zero or low-carbon electricity – offer the most direct opportunity to decarbonise road transport over the longer term. In addition to CO_2 and running cost benefits, electric vehicles do not emit any regulated pollutants at the point of use, and can offer other advantages such as good low speed acceleration. Recent developments in battery technology raise the expectation that, in the longer term, batteries could offer acceptable range, performance and recharging time.

Electric vehicles are already on the road

4.48 Electric vehicles are more expensive to purchase than petrol or diesel equivalents, but when their lower running costs are taken into account they are cost-effective for some types of user. Battery-electric vans such as the Modec and the Smith are already available, and are suited to environments where daily mileages are 100-150 miles or less, such as urban deliveries. The G-Wiz vehicle sold by GoinGreen offers suitable range and performance for low-speed urban motoring, and it is cost-effective for motorists in supportive environments, such as some London boroughs where it is exempt from congestion and parking charges.

4.49 Vehicles that have higher top speed and range, such as the EV Smart for 2 (being developed for Mercedes by the UK company Zytek), are at the stage of demonstration in a small fleet, and the challenges are to test the durability of these and bring them to market at sufficiently low cost. Table 4.4 illustrates the state of some current technology.

Table 4.4: Electric vehicle performance

Vehicle	Technology readiness	Range	Recharging time	Top speed
G-Wiz	Available today	48 miles	2hrs 30 mins – 8hrs	45 mph
EV Smart for 2	Small fleet	62 miles	3hrs 30 mins – 8hrs	74 mph
Tesla 2-seater sports car	Prototype validated – deployment expected to commence 2008	200 miles	3hrs 30 mins – 8hrs	130 mph
Modec commercial vehicle	In production	100+ miles	Overnight	50 mph
Smith electric van range	In production	Up to 150 miles	Overnight	50 mph

Table compiled from manufacturers' information.

Challenges for electric technologies

4.50 Although Table 4.4 shows that electric vehicles that are suitable for some users are already on the road, sales of these vehicles are likely to remain confined to niche markets until substantial battery challenges have been overcome. Batteries that have higher energy density are needed to deliver greater range. There are also engineering challenges in the integration and management of newer battery technologies within vehicles, and in achieving acceptable battery cost and life. Box 4.2 summarises existing battery technologies and these challenges.

Box 4.2: The battery technology challenge

The continued development of battery technologies is necessary in order to ensure that hybrid and plug-in hybrids are cost-effective options for consumers. The most important battery types at the moment are set out below.

Lead-acid batteries are very heavy, with low energy density, but are readily available and inexpensive, so could be a cost effective solution for hybrid vehicles.

Nickel-Metal Hydride (NiMH) is generally used for the current generation of hybrid vehicles such as the Toyota Prius. These batteries have a higher energy density than lead acid batteries leading to ranges up to 200 kilometres (120 miles).

Lithium-ion batteries are commonly used for portable electronics such as laptops and mobile phones as they have a relatively high energy to weight ratio. Lithium-ion electric vehicles could offer 400-500 kilometres (250-300 miles) of range per charge. However, further development, particularly around system integration and battery management, is required before this class of battery can be deployed with confidence in the automotive sector.

The future of battery-electric vehicles depends primarily upon the cost and availability of batteries with high power density and long life. This is a major technology challenge.

Sources: An overview of hybrid technologies, Ricardo, 2007; RHOLAB Project, Foresight Vehicle.

Hydrogen-powered vehicles

Hydrogen is a possible future alternative

4.51 Hydrogen can be used in cars, either by being burnt in an internal combustion engine, or by generating electricity in a fuel cell. In fuel cells, hydrogen (or a hydrogen-rich fuel) is chemically converted into water, electricity and heat. Similarly, when hydrogen is burnt in or reacted with oxygen, the only by-product is water, typically in the form of steam. Therefore, like electricity, hydrogen offers the potential advantage that it creates no harmful emissions at the point of use and its life-cycle CO_2 emissions are largely determined by how it is sourced. These processes are also highly efficient, although converting hydrogen to electrical power in a fuel cell is more efficient than burning it in an internal combustion engine.[10] There are many potential applications of fuel cell technologies and, although applications in small vehicles such as cars are generally considered to be the furthest from commercial deployment, there are currently a number of prototype fuel cell demonstration vehicles, as Box 4.3 illustrates.

Box 4.3: Prototype hydrogen fuel cell vehicles

Fuel cell cars are currently at the prototype technology demonstration stage. A number of major automotive companies including BMW, GM, Ford and Honda have developed such concepts. Production of a single prototype hydrogen fuel cell vehicle typically costs between £0.5 million and £1 million.

Other automotive applications of fuel cells can prove important in demonstrating the technology and overcoming technical hurdles. The UK fuel cell company Intelligent Energy developed the world's first hydrogen fuel cell motorbike. The ENV bike is powered by a 1 kW fuel cell, has a top speed of 50 mph and a range of 100 miles. Intelligent Energy has formed a strategic relationship with Suzuki in order to develop the concept further. The company also has a relationship with PSA Peugeot Citroën, with whom it is developing automotive fuel cell systems.

Hydrogen poses technological challenges

4.52 However, as with electric vehicles, there are a number of major challenges to overcome. Hydrogen storage on a vehicle is problematic because, in order to achieve a reasonable energy density, it must currently be stored as a liquid at low temperature or as a compressed gas, the latter requiring a large and expensive tank. Research is ongoing into solid-state storage. In addition, hydrogen is a very small molecule, especially in comparison to hydrocarbon fuels, and sealing in a pressurised system is a major challenge. Apart from the issue of hydrogen storage, the other main challenges for automotive fuel cell development are reducing substantially the cost of the fuel cell (as this currently contains expensive materials), improving performance and ensuring durability.

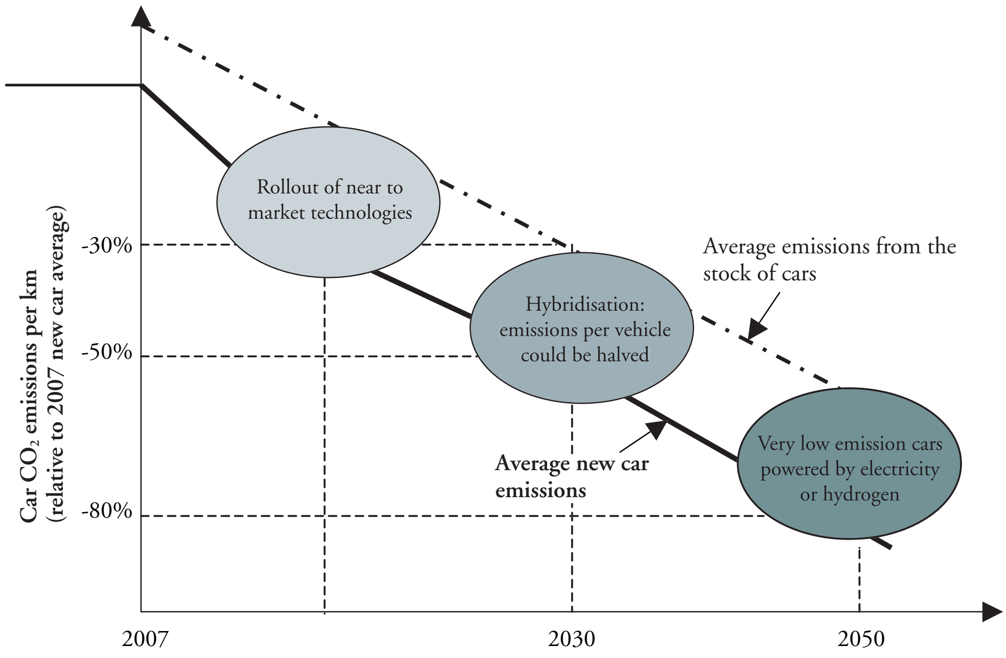
4.53 Cost, complexity, fuel distribution and storage, and the absence of low-CO_2 sources of hydrogen, mean that hydrogen technologies are unlikely to be a major contributor to reducing automotive CO_2 emissions in the short to medium term. However, in the long term, hydrogen fuel cells could be an important option if the breakthroughs in battery technology needed for future electric vehicles are not forthcoming.

[10] *A strategic framework for hydrogen energy in the UK,* E4tech, Element Energy, Eoin Lees, 2004.

THE TECHNOLOGY PATHWAY

4.54 It is difficult to forecast with accuracy which technologies will prevail technically or commercially. Chart 4.2 summarises one potential path for low-carbon vehicle technologies and the impact this could have on per-kilometre CO_2 emissions:

Chart 4.2: Potential technology pathway for low-carbon vehicles



4.55 In the short term, there are several technologies that are already close to market and could together deliver CO_2 reductions for new cars of around 30 per cent within 5-10 years. The immediate challenge is to create a strong market for such vehicles and to get cars with these benefits into showrooms and onto the road as quickly as possible. In the medium term (from around 2020) much more extensive use of electric-hybrid propulsion systems is the likely route for further emissions reductions, with plug-in hybrids becoming more common.

4.56 Subject to substantial progress on meeting battery and/or fuel cell challenges, and delivering clean fuels, very low-emission cars powered by electricity or hydrogen could be standard by 2050. If neither batteries nor hydrogen can deliver the necessary advances, very advanced biofuels offer some potential, as discussed in Chapter 3. All three routes involve some exciting, long-term research challenges and there are opportunities for the UK science base to make important contributions, which could put the UK in a strong competitive position.

MAXIMISING THE CONTRIBUTION OF UK SKILLS AND EXPERTISE TO THE GLOBAL EFFORT

4.57 CO_2 reduction is a global challenge and the car industry operates globally. No country is likely to produce all the solutions. However, as well as playing a strong role in coordinating international action on road transport, the UK can choose to be a leading innovator as well as a lead market for the deployment of these technologies.

The UK automotive sector contributes £9bn a year

4.58 Some 210,000 people are employed in the UK automotive manufacturing sector. The industry contributes £9 billion added value to the economy, and accounts for 6.2 per cent of manufacturing value-added and 11 per cent of total UK manufacturing exports. The UK is a major engine manufacturer, producing an estimated 3 million units a year, some 25-30 per cent of European production. The manufacturing base includes the volume car producers BMW (Mini), Ford, Jaguar Land Rover, Honda, Nissan, Toyota and GM (Vauxhall), as well as a range of smaller producers serving specialist markets such as sports and luxury cars (e.g. Bentley and Lotus).[11]

4.59 The UK has significant engine production and vehicle assembly assets, as well as a strong research capability. International vehicle manufacturers make use of the UK's world-class design, development and strategic consulting firms, academic teams, and specialist component suppliers.[12] Vehicle manufacturers are also served by automotive engineering consultancies, which play an increasing part in powertrain developments.

Opportunities for the UK

4.60 The key challenges are to ensure that the UK is well-placed to develop and exploit commercially successful technologies, achieving a good financial return on knowledge. Opportunities exist for the UK to benefit by:

- being a leading location for high-tech powertrain manufacturing;
- making breakthroughs on the long term technological challenges, such as in battery technology; and
- demonstrating and improving the most advanced technologies and licensing them to manufacturers.

4.61 The UK Government supports the development and demonstration of low-carbon technology through a number of mechanisms. Part II of the King Review will address the question of UK strengths, challenges and opportunities in more detail and will consider possible policy recommendations concerning the development of low-carbon vehicle technology. It will also consider how to ensure the benefits of close-to-market technologies are realised early and cost-effectively.

CONCLUSIONS

4.62 Significant reductions, of the order of 30 per cent, in emissions from internal combustion engines are technically feasible for cars entering production within the next 5-10 years. This is achievable provided the emissions reducing potential of this technology is not simply eroded by the trend to purchase larger vehicles with more energy-consuming features. These technologies would add to the production cost of vehicles, but any increase could be recovered in fuel savings over the life of the vehicle. However, such vehicles will not come to market across a wide range of vehicle types unless sufficient consumer demand can be demonstrated. The biggest challenge is to ensure that manufacturers see an international market for these vehicles and are prepared to produce them on a large scale.

4.63 In the medium term, electric-hybrid vehicle technology probably offers the best prospect of reducing CO_2 emissions further. In the longer term, it is more difficult to forecast which technologies will prevail, technically or commercially. Battery-electric cars seem a logical engineering solution, emitting no pollutants when driven and with a very low overall CO_2 footprint if the electricity used to charge the battery is generated sustainably. However, significant advances in battery science and technology need to be delivered. Hydrogen, if generated

[11] *A study of the UK automotive engine industry,* DTI, 2005.
[12] *A review of the UK innovation system for low carbon road transport technologies,* E4tech, 2007.

sustainably, could be another clean way of supplying energy in a vehicle. Challenges for hydrogen-powered vehicles include sustainable hydrogen generation and distribution, hydrogen storage and system cost.

5 Consumer choices

KEY MESSAGES

CO_2 savings of 10-15% can be achieved from consumer choices

5.1 Realising the benefits of low-carbon vehicle and fuel technologies is dependent on their successful adoption. Consumers – through their choices of what to drive and how to drive – can make a substantial difference now to reduce CO_2 from road transport. The Review estimates that CO_2 savings of 10-15 per cent over the next 5-10 years could come from consumer choices, and these benefits can begin to be realised now. Many small things can have a significant cumulative impact:

- **demanding new technologies** – consumers in all market segments can make a difference through their vehicle choices. Just choosing the most fuel-efficient model in the range or market sector can reduce a driver's CO_2 emissions by a quarter[1]. Selecting a diesel engine of comparable performance, rather than size, can reduce a driver's emissions by around 15 per cent[2]. Beyond this, consumer demand for more radical reductions in emissions will bring low-carbon technologies to market earlier. If preferences change in future, and some people start downsizing their vehicles on environmental grounds, potential savings are even greater; and
- **getting the most out of vehicles** – simple aspects of driver efficiency such as, keeping tyres pumped up, not accelerating too fast, moderating motorway speed and minimising weight, can make a real difference to fuel consumption and CO_2 emissions. There may also be some scope for marginal reductions in CO_2 emissions through increased walking, cycling, lift sharing and use of public transport, without material inconvenience.

Financial savings as well as CO_2 savings

5.2 Such changes would be beneficial for the environment but, importantly, would also benefit individuals. Improvements in vehicle efficiency and driver efficiency deliver equivalent financial savings from motoring costs as well as CO_2 reductions.

Challenges for consumer choices

5.3 Demand for motoring is increasing as incomes grow. Currently around 60 million cars are manufactured each year worldwide and this is predicted to grow to 80 million by 2020[3]. While growth rates in the UK are slower than in emerging economies such as China and India, the number of private cars still grew by around 13 per cent in the UK between 2000 and 2005[4]. This growth in demand makes the choices of which car to buy and how to drive it increasingly important. At present people in the UK express a high level of concern about the environment and the impact of global warming, but this is far from fully reflected in their car purchasing decisions and car use. There is a large gap between attitude and action. Consumers discount heavily future cost savings from fuel efficiency at the time of buying a new car. In addition, environmental or fuel efficiency considerations do not appear to play a large role in shaping the way in which people

[1] *Act on CO_2*, Department for Transport.
[2] *Annual CO_2 Report 2006*, SMMT, 2007.
[3] Management Today, October 2007.
[4] *Transport Statistics*, Department for Transport.

drive. This presents challenges, but also highlights the potential opportunities for reducing carbon emissions through smarter consumer choices. This chapter identifies a number of choices that can have a quick and substantial impact on CO_2 emissions.

INTRODUCTION

5.4 Technology achieves nothing if it is not adopted. The significant potential for CO_2 savings from cleaner fuels, and particularly more efficient vehicles, is dependent on the willingness of consumers to demand these lower-carbon options and use them efficiently. As Chapter 4 indicates, it is technically feasible, and potentially cost-effective, for new cars to be 30 per cent more efficient (on a like-for-like basis) within 5-10 years. However, the roll-out of these technologies will depend on there being a market that is keen to adopt them, and eager to realise the private cost benefits of more efficient vehicles.

5.5 Advances in technology help ensure that it is not necessary for people to make costly or inconvenient life-style changes in order to reduce their CO_2 emissions. Road transport will continue to be important to economic growth and mobility and, for all road users, technological advances mean that the lower-carbon option is increasingly available now.

5.6 It is not just in choosing a particular vehicle technology that an individual determines their CO_2 emissions. It also depends how efficiently people operate their vehicles and how much they choose to use them.

5.7 This chapter looks at how important these consumer choices are for overall CO_2 emissions, particularly in the shorter term. It sets out the nature of consumer preferences in road transport and some of the challenges in realising CO_2 savings. It then looks at the great potential for CO_2 emissions reduction from people's choices, and how all consumers can make a difference in bringing new technologies to market and maximising the impact of those new technologies in reducing carbon emissions.

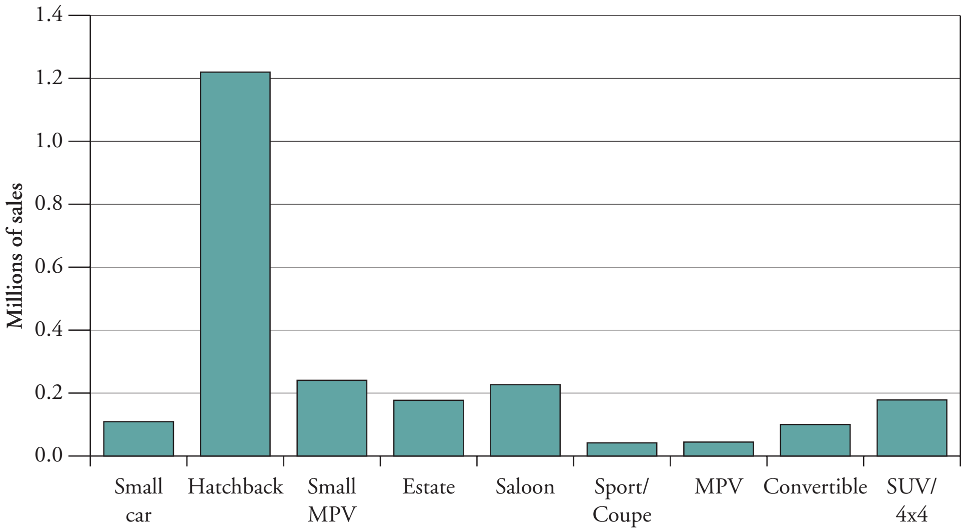
CONSUMER PREFERENCES IN ROAD TRANSPORT

Box 5.1: UK car consumers

There are 30.6 million cars in the UK. Overall around 120 million tonnes of CO_2 is emitted from road transport each year, of which passenger cars account for almost 60 per cent. Passenger cars represent an eighth of the UK's total carbon footprint.

In the UK, hatchbacks are by far the most popular type of vehicle, with over 1.2 million new purchases in 2006. High-polluting classes of vehicle, such as sports cars and SUVs, sell in much lower numbers. It is therefore important that consumers in all segments make a contribution to reducing CO_2 emissions.

Chart 5.1: UK car sales by new vehicle type in 2006



Source: Department for Transport (unpublished)

5.8 Although there is significant potential to achieve CO_2 savings from consumer choices, realising them is likely to be challenging for several reasons:

- as demand for motoring is strongly linked to economic growth, overall efficiencies must be achieved in the context of increased vehicle use;
- preferences are robust to change and there currently appears to be a wide gap between environmental attitudes and actions; and
- consumers tend to discount heavily fuel efficiency savings in their vehicle purchase decisions.

[5] *National Travel Survey*, Department for Transport, 2006.

Over time, people will demand more road travel

5.9 Demand for road transport is closely linked to economic growth. Consumers value cars, and the personal freedom associated with driving, highly. As the economy continues to grow and incomes rise, people are likely to want to increase their spending on motoring. At present, around 25 per cent of UK households do not have access to a car and evidence suggests that people without cars are very keen to acquire them. Recent surveys suggest that people without cars will spend around three quarters of any increase in income on buying a car[6]. In this context of growing demand for motoring, emissions reductions are unlikely to be achieved through overall reductions in distance travelled (although, at the margin, where people can substitute walking, cycling or public transport for some car journeys, consumer choices can play a part). This places even more importance on reducing CO_2 from choosing low-carbon vehicles and driving them efficiently.

Environment is a minor factor in many car purchase decisions

5.10 People's high level of expressed concern about the environment is not generally reflected in their car purchasing and use. As Box 5.2 shows, people tend to purchase cars on the basis of up-front price, reliability, comfort and safety. Environmental concerns do not figure highly. Traditional preferences such as appearance, power, image and brand still feature much more strongly in people's decision-making than the environment and emissions.

Box 5.2: Factors that are important to consumers in deciding which car to buy

Most important	Medium importance	Least important
Vehicle price	Performance	Depreciation
Size	Power	Sales package
Reliability	Image	Personal experience
Comfort	Brand name	Dealership
Safety	Insurance costs	Insurance cost
Running costs	Engine size	Engine size
Fuel consumption	Equipment	Equipment
Appearance		Recommendation
		Road tax
		Environment
		Recommendation
		Road tax
		Environment
		Vehicle emissions
		Alternative fuel

Source: LowCVP Car Buyer Research Report.

Consumers discount the benefits of fuel economy

5.11 The amount of CO_2 emitted depends directly on the amount of fuel consumed (see Box 5.3), so, from an environmental perspective, it is encouraging that fuel consumption is identified as one of the most important factors when deciding what car to buy. However, in practice, purchase decisions suggest that consumers take a very short-term view when weighing up vehicle purchase costs. On average, consumers apply a very high discount rate (60 per cent)[7], which implies that they are looking to an 18-month payback period for fuel costs[8]. Moreover, the average motorist underestimates their car running costs by around a factor of two[9]. Greater awareness of the link between CO_2 emissions and fuel use, and of the real cost of running a car, has potential to enable choices (both in choosing and using a vehicle) that would be better for both the motorist and the environment.

[6] *Review of price elasticities of demand for road traffic,* Glaister and Graham, 2002.
[7] BP modelling.
[8] Presentation by the Center for Clean Air Policy, 2005.
[9] *RAC Report on Motoring 2004*, RAC, 2004.

5.12 There are some positive signs that preferences are beginning to change. There has been a recent decline in popularity of some overtly high-polluting vehicles. As attitudes change, manufacturers are increasingly emphasising their environmental credentials and bringing out some "green" models. If an increasing number of consumers move towards "greener" models over the next few years it should be possible to deliver substantial CO_2 reductions while continuing to realise the economic and other benefits of car use.

SCOPE FOR NEW CHOICES

Choosing and Using

5.13 Choices by consumers can have a significant impact on CO_2 emissions, without the need for a step-change in preferences. For many drivers, there are potentially attractive choices that can make a marked difference to their carbon footprint, as well as delivering fuel cost savings. The attractive choice may be different in each individual case, whether it is choosing the right type of vehicle, adopting an efficient vehicle in its class, operating vehicles in an efficient manner, or a comination of these. The Review estimates that overall CO_2 savings of 10-15 per cent could be achieved from consumer choices within 5-10 years. As these choices are available now, these benefits can begin to be realised immediately.

5.14 This section sets out the two main areas in which road users can reduce their CO_2 emissions:

- **choosing cars**, both in selecting the type of vehicle and the particular model in any vehicle class; and
- **using cars**, where "efficient driving" can make a significant difference and there may be some scope to reduce mileage on marginal journeys.

5.15 As well as offering immediate benefits to both the environment and the consumer, through greater fuel efficiency, these choices would also strengthen market signals to manufacturers about the demand for new low-carbon technologies. This would help to pull through CO_2-saving technologies to the market, starting to pave the way for further decarbonisation of road transport in the future.

Choosing cars

5.16 Realising the benefits of the low-carbon technologies discussed in Chapter 4 depends on consumers' choices. Many of these technologies are already available and CO_2 emissions (and, as Box 5.3 explains, running costs) vary widely depending on the vehicle driven. At the extremes, a powerful sports car or SUV can emit 3 or 4 times as much CO_2 per kilometre travelled (and therefore costs 3 or 4 times as much in fuel) as an efficient small car[10]. Emissions tend to vary according to the class of the vehicle, as well as there being substantial variance between different vehicles within classes.

[10] See Chart 5.3.

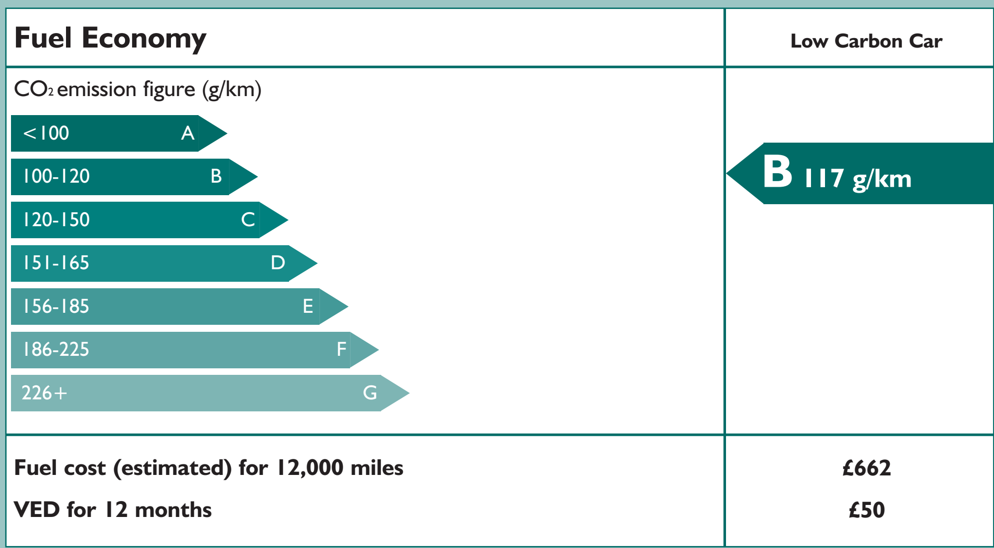
Box 5.3: The link between fuel economy and CO_2 emissions

CO_2 emissions from a car's exhaust are directly related to the quantity of fuel used, which in turn is directly related to the efficiency with which fuel is used by the vehicle (often referred to as "fuel economy").

Consequently, improving efficiency either by choosing a more fuel-efficient vehicle or by driving a vehicle in a more fuel-efficient manner achieves two things:

- financial savings from lower fuel use, for any given distance travelled; and
- equivalent reductions in CO_2 emissions as a result of the lower fuel use.

For someone driving 10,000 miles a year, a 20 per cent fuel efficiency saving equates to over £200 a year in fuel savings and half a tonne of CO_2 emissions reductions[11]. The Department for Transport's emissions labelling for new cars, illustrated below, sets out indicative fuel economy figures and shows the implications of this for fuel costs and CO_2 emissions.



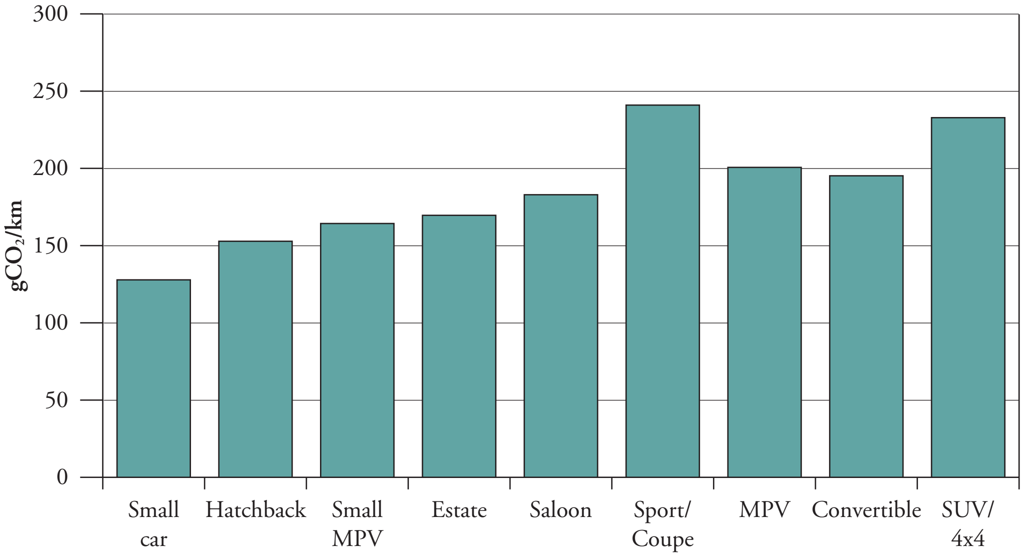
Class of car

5.17 Class of car is a major efficiency driver for CO_2 emissions. As Chart 5.2 illustrates, there is a wide range in emissions between different classes of car: for example, on average an SUV has 70 per cent more emissions than a small car. Depending on the particular models in question, selecting a vehicle one class below (for example, moving from a diesel Ford Focus to a diesel Ford Fiesta), would on average reduce a driver's CO_2 emissions by nearly 15 per cent[12].

[11] King Review calculations, based on Vehicle Certification Agency car fuel data.

[12] *SMMT Annual CO_2 Report – 2006 Market*, The Society of Motor Manufacturers and Traders Ltd, 2007.

Chart 5.2: Average emissions by new vehicle type in 2006



Source: DfT (unpublished)

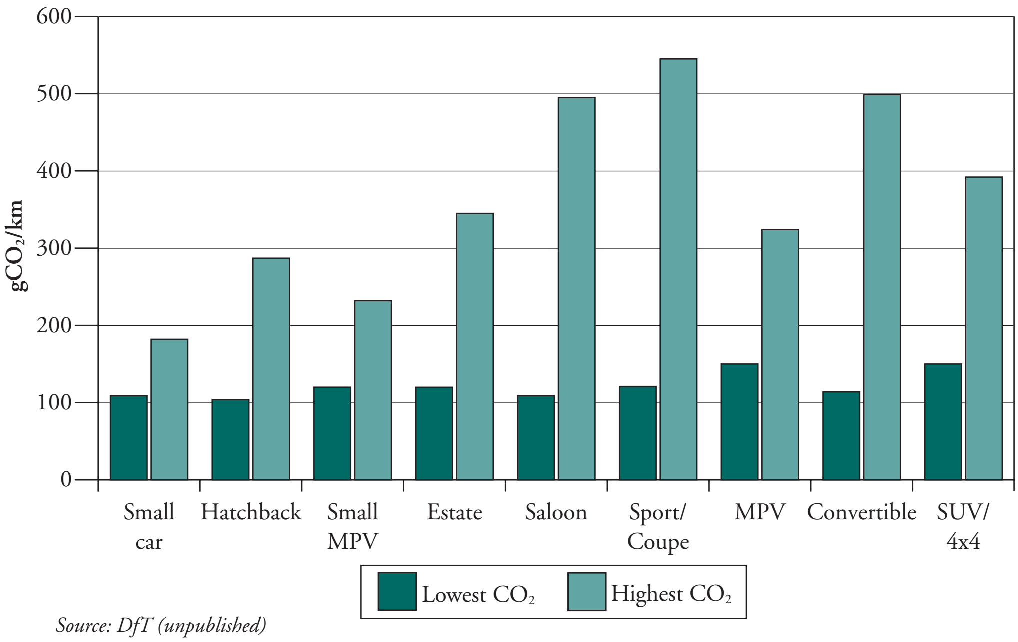
5.18 Car-buying decisions are made on the basis of a multitude of factors, and for many people it will continue to be the right choice to drive larger vehicles. In practice, only a small proportion of people are likely to be in a position to make a shift between car classes but, for those able to do so, moving to a smaller class of car brings significant fuel savings and an important contribution towards reducing CO_2 emissions from road transport.

Choices make a difference, whatever the class of vehicle

5.19 Although many people will have a clear preference for a particular class (or type) of car, others will be less decided about which vehicle to choose within that class. Typically, people will be choosing between different models in a range, or similar models across different manufacturers. This decision – about which specific car in a given class or type to go for – can make a substantial difference to fuel economy and CO_2 emissions.

5.20 There is a significant range of emissions within every class or type (see Chart 5.3). For example, some new SUVs have CO_2 emissions of around 150g per kilometre, below the UK new car average, while others in the same class have emissions of around 400g per kilometre. In the most popular hatchback class, where over one million new vehicles are sold annually in the UK, emissions range from around 100g per kilometre to almost 300g per kilometre, depending on the make and model chosen and the technologies used. This highlights the significance of car choice for all consumers, whatever the type of vehicle.

Chart 5.3: Range of Emissions by Vehicle Class in 2006



Source: DfT (unpublished)

"Best in class" reduces average emissions by a quarter

5.21 According to Department for Transport data[13], choosing the lowest emitter (rather than the average) in any market segment will tend to make a difference of about 25 per cent to fuel efficiency and CO_2 emissions. For a household driving 10,000 miles a year, this would reduce the fuel bill by around £25 per month. Similarly, moving down an engine size typically sees a reduction of around 5 per cent in fuel consumption and CO_2 emissions. Vehicle comparison tables, which identify the most fuel-efficient cars in each class, are published on the DfT website[14].

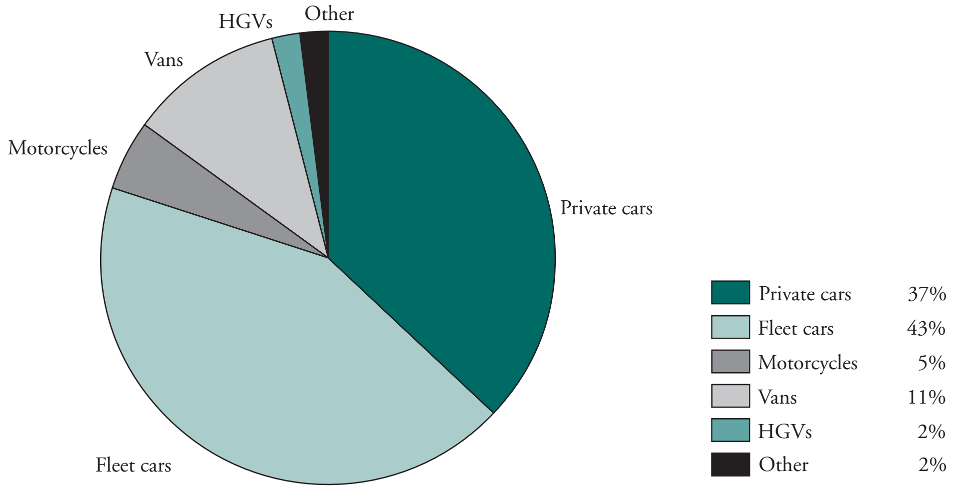
Petrol and diesel

5.22 The choice between petrol and diesel also has a direct effect on emissions. Diesel cars are currently around 10-20 per cent more fuel-efficient than equivalent petrol models[15], which means there is a similar potential for reducing CO_2 emissions.

[13] *Act On CO_2*, Department for Transport.
[14] www.dft.gov.uk
[15] *SMMT Annual CO_2 Report – 2006 Market,* The Society of Motor Manufacturers and Traders Ltd, 2007.

Box 5.4: Fleet purchases and vans

UK new vehicle purchases by type in 2006-07



Source: DfT.

The fleet market includes rental, car leasing and personal company cars and accounts for over half (56 per cent in 2006) of new car registrations in the UK, equating to around 1.3 million new registrations.

Although the profile of fleet models tends to differ little from private car purchases, largely because second hand car values underpin both sets of buying decisions, there may be some additional scope for environmental choices:

- environmental responsibility is closely aligned with corporate responsibility; and
- fleets are often in a good position to adopt new technologies as they can benefit from economies of scale in procurement and maintenance.

Vans account for over 12 per cent of the stock of fleet/business vehicles. Many of the smart choices available to car drivers also apply in the van market:

- choice of van makes a difference to CO_2 emissions. Van emissions vary within a market segment, although there is currently no formal certification of vehicle efficiencies, and differences between diesel and petrol models apply;
- because some van fleets (e.g. delivery vehicles and public fleets) regularly operate on a smaller range, there is scope for them to be early-adopters of electric vehicles; and
- efficient driving can be even more important in vans, which typically carry more weight. Studies suggest that smart van driving can reduce a vehicle's CO_2 emissions and running cost by around 10 per cent.[16]

Using cars

5.23 Although the choice of vehicle is a major factor in determining a driver's CO_2 emissions, there is a further set of choices available to the consumer concerning use of the car. Both the manner in which a car is driven and the journeys for which it is used will contribute to the final level of emissions – determining whether a driver is making the most efficient use of technologies.

[16] Based on pilot study by SAFED For Vans.

Efficient driving can substantially reduce a driver's emissions

5.24 Efficient driving makes a big difference. Car technologies are designed to run within particular ranges of mechanical conditions and deviations from these have a negative effect on fuel efficiency and CO_2 emissions. Excessive acceleration and braking, driving at very high speed and inappropriate use of gears incur substantial fuel and environmental costs.

5.25 There are a number of other factors under the control of the driver that can make a difference. While air conditioning is being used it can add up to 25 per cent to fuel consumption and CO_2 emissions[17]. An empty roof rack can create significant drag. Box 5.5 summarises the Department for Transport's tips for smarter driving, which include driving at appropriate speeds and carrying less clutter in the car. DfT estimates that smarter driving can immediately reduce emissions from cars, and fuel consumption, by 8 per cent[18], while other studies have indicated that, over time, drivers could achieve efficiency savings of as much as 10-15 per cent[19].

Box 5.5: Smarter driving tips

"Pump up to cut down"

Under inflated tyres create more resistance when your car is moving, which means your engine has to work harder, so more fuel is used and more CO_2 emissions are produced. Simply check and adjust your tyre pressures regularly and also before long journeys. This will also help to increase the life of your tyres. Under-inflated tyres increase CO_2 but over inflated tyres can be unsafe so check your car manual for the correct tyre pressure. Remember, a car with a heavier load may need different air pressure in the tyres.

"Less clutter in your car means less CO_2"

Clutter in your boot is extra weight your engine has to lug around. By removing it, you could reduce your engine's workload. This will burn less fuel and cut your CO_2 emissions so unload any items you won't need for your journey before you set out.

"Driving at an appropriate speed reduces CO_2"

Speed limits are the maximum lawful speeds which may be driven in ideal circumstances. Drivers should never exceed the speed limit. Staying at or within the speed limit increases driver safety. It also reduces CO_2 emissions and saves money on your petrol costs. At 70mph you could be using up to 9 per cent more fuel than at 60mph and up to 15 per cent more fuel than at 50mph.

"Less stopping and starting means less CO_2"

Every time you stop then start again in a traffic queue, the engine uses more fuel and therefore produces more CO_2. Keep an eye on the traffic ahead and slow down early by gently lifting your foot off the accelerator while keeping the car in gear. In this way, the traffic may have started moving again by the time you approach the vehicle in front, so you can then change gear and be on your way.

"Over revving accelerates emissions"

Modern car engines are designed to be efficient from the moment they are switched on, so revving up like a Formula 1 car in pole position only wastes fuel and increases engine wear.

Using your gears wisely by changing up a gear a little earlier can also reduce revs. If you drive a diesel car try changing up a gear when the rev counter reaches 2000rpm. For a petrol car change up at 2500rpm.

"Idling is wasting fuel"

When the engine is idling you're wasting fuel and adding to CO_2 emissions. If you're likely to be at a standstill for more than 3 minutes, simply switch off the engine.

Source: Department for Transport Act on CO_2 (www.dft.gov.uk/actonco2)

[17] *Treatise, Ecodriving,* Energy Saving Trust, 2005.
[18] *Act on CO_2,* Department for Transport.
[19] *Treatise, Ecodriving,* Energy Saving Trust, 2005.

5.26 As technology develops, many of these driving efficiencies will become electronically automated in cars, helping drivers to realise these savings. However, it takes over a decade to replace the whole car stock so, in the shorter term, the measures above will remain important.

5.27 Congestion is another factor that significantly affects driving efficiency. The Eddington Transport Study[20] concluded that almost 30 per cent of travel time in major urban areas during peak periods is spent at speeds below 5 mph and over 50 per cent at spends of less than 20 mph. Reducing and avoiding congestion would, therefore, reduce emissions as well as saving the time of drivers and passengers. Road pricing and in-car technologies that provide more detailed driver diagnostics will facilitate this, as well as potentially helping to provide an accurate measure of driver efficiency in future.

Mileage trends

5.28 The extent to which people use their cars and the distance they travel directly influences total emissions. As has previously been noted, road travel is an important contributor to economic growth and mobility. Given this, it is likely that road use will continue to increase in the years ahead as the UK and world economy continues to grow.

5.29 The Eddington Transport Study projected a large increase in kilometres travelled over the period to 2025 in the UK. Under the central scenario it predicts vehicle kilometres up by 28 per cent and passenger vehicle kilometres up 17 per cent[21] between 2003 and 2025. This demand will be fuelled mainly by a rising population and increasing household incomes. It is generally preferable for emissions reductions to be achieved from improvements in vehicle, fuel and driving efficiency, rather than by reducing travel. However, there may be some potential to reduce car use for low-value trips at the margin, where people are easily able to substitute walking, cycling or use of public transport.

Short journeys

5.30 Nearly a quarter of car journeys are less than two miles. Over the last 10 years the number of walking trips per year, and the average distance travelled by bicycle, have each fallen by 16 per cent[22]. If these trends were reversed, there would be positive effects on CO_2 emissions, congestion and public health.

Other measures

5.31 Other choices people can make that can reduce their CO_2 emissions include using public transport, car sharing, car clubs, working from home and combining trips.

Total potential of consumer choices

5.32 Whether in choosing or using a car, technological advances mean that consumers invariably have available to them a number of options to improve their fuel efficiency, saving themselves money and reducing CO_2 emissions. Through sensible choices, the Review estimates that a reduction in CO_2 emissions of 10-15 per cent can be achieved by consumer choices alone over the next 5-10 years (see Box 5.6). In playing their part, consumers can also influence innovation in low-carbon vehicle and fuel technologies, ensuring these technologies reach the market as early as possible.

[20] *Eddington Transport Study*, 2006.
[21] The differential reflects a projected decline in average vehicle occupancy.
[22] *National Travel Survey 2005*, Department for Transport.

Box 5.6: Summary of potential of consumer choices

Choosing cars

Choosing the appropriate class of car: opting for the class below reduces emissions by around 15 per cent.

Choosing a low-carbon car in its class: going for "best in class" reduces emissions by around 25 per cent.

Using cars

Efficient driving techniques can reduce emissions by up to 15 per cent.

Avoiding low-value journeys, or finding alternative forms of transport, also makes a difference.

These choices all offer savings to the motorist from lower fuel costs.

Overall, the Review anticipates that, as motorists increasingly make these smart environmental choices, total CO_2 savings of 10-15 per cent from consumer choices can be achieved over the next 5-10 years.

CONCLUSION

5.33 Consumer choices are important in maximising the impact of progress in vehicle and fuel technologies. They can also make a big impact in their own right. This chapter shows that if consumers make careful choices about the type of model they buy, and the way in which they use their cars, they could substantially reduce their emissions. These changes can start immediately.

6 Pathway to the future

INTRODUCTION

6.1 This chapter pulls together Chapters 3, 4 and 5 and discusses the scope for cutting CO_2 from road transport.

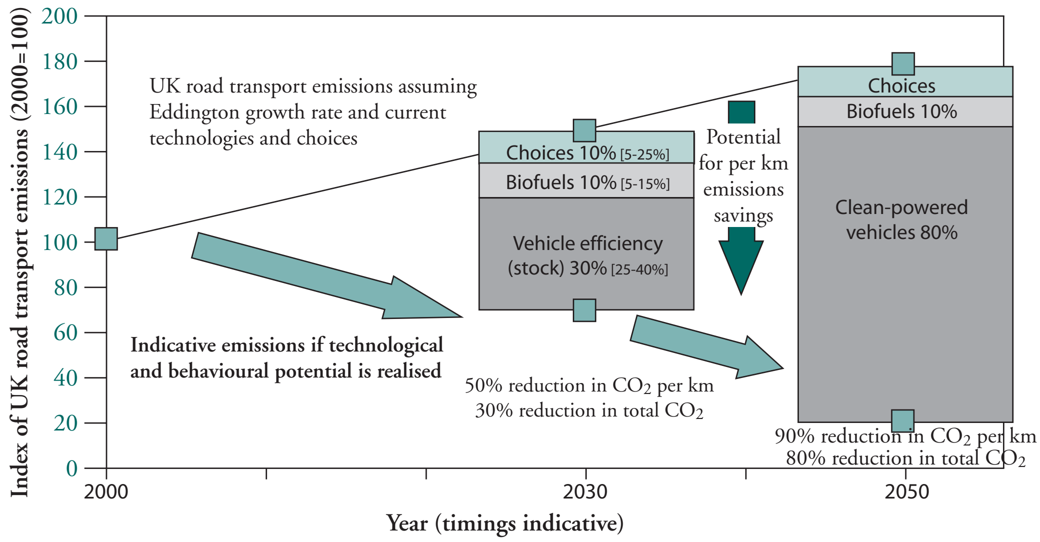
A PATHWAY TOWARDS DECARBONISING ROAD TRANSPORT

6.1 The challenge for road transport is to achieve early, substantial cuts in CO_2 emissions, moving towards the ultimate ambition of "decarbonising" the sector. This will need to be achieved in the context of expected increases in overall transport demand, underpinning continued and sustained economic growth and increased personal mobility. Despite this, substantial reductions in CO_2 from road transport can be achieved through progress in the three key areas this Review covers:

- cleaner fuels;
- more efficient vehicles; and
- consumer choices.

6.2 While this Review cannot forecast with confidence the future path of technological development and recognises the importance of not picking those technologies that will prevail, the following sets out one possible pathway to achieving major reductions in CO_2 from UK road transport by 2050. It identifies the nature of changes possible in the short term (next ten years), the medium term (2030) and the long term (2050 and beyond), giving an illustration of the potential scale of CO_2 reductions, set against a baseline of expanding travel demand.

Chart 6.1: A pathway towards decarbonising road transport



Short term potential

6.3 Over the next few years, significant CO_2 reductions could be achieved, at very low cost, through use of fuel and vehicle technologies that are already available, and by making smart consumer choices. The CO_2 efficiency of new vehicles sold could be improved by 30 per cent in 5-10 years, with near to market technology. This could be cost-effective to the consumer if adopted on a large scale. Limited expansion of biofuels in the fuel mix can contribute to a small reduction in CO_2. More significant gains could be made if consumers make smart choices (for example, by buying the most efficient vehicle in their chosen class and adopting efficient driving techniques). The following summarises the potential for progress in the short term:

- fuels – small increase in biofuel use, providing marginal reductions in CO_2;
- vehicles – 30 per cent improvements in new car efficiency in 5-10 years, if technologies can be brought to market; and
- consumer choices – smarter purchases and driving can deliver significant CO_2 savings.

Potential for 2030

6.5 By 2030, more efficient internal combustion engines could have achieved significant fleet penetration and significant use of hybrids is possible. Biofuels might be expected to meet around a fifth of total fuel demand, subject to technological advances and meeting environmental sustainability criteria. Assuming the life-cycle emissions of these biofuels are at least 50-75 per cent lower than petrol and diesel, this represents a CO_2 efficiency saving of at least 10 per cent per kilometre.

6.6 The overall effect of these changes could be to reduce CO_2 per kilometre by 50 per cent (and total car CO2 emissions by about 30 per cent, taking increased demand into account)[1]:

- fuels – expansion of biofuels providing per-kilometre CO_2 savings of approximately 10 per cent;
- vehicles – penetration of more efficient vehicles could reduce emissions across the fleet by 30 per cent per kilometre; and
- consumer choices – reduction in per-kilometre emissions of at least 10 per cent, from continued changes in purchasing behaviour and improved driving efficiency.

Long term potential

6.7 In the longer term, possibly by 2050, almost complete decarbonisation of road transport is possible. This will require breakthroughs in battery and/or hydrogen technology and a zero-carbon power source for these vehicles.

[1] The potential for carbon savings through changes in any one of the three main areas covered in this Review (fuels, vehicles, consumer choices) is directly affected by potential changes in the other two. For example, the more carbon-inefficient the average car is, the larger the potential for efficiency savings through more efficient driving of those cars. The calculations here are additive. They take account of these interrelations and are mutually consistent to avoid any double counting which could overestimate the potential for savings. If lower efficiencies are achieved in one area, the potential for savings in another could rise. For example, in the long term scenario, if there were fewer vehicles powered by electricity or hydrogen, much more might be achieved by biofuels.

6.8 Between 2030 and 2050, CO_2 reduction from cars could be accelerated as electric and/or hydrogen vehicles come into the fleet and more clean power becomes available. Depending on the UK power sector mix, this combination of vehicle and fuel developments could provide per-kilometre CO_2 savings of as much as 80 per cent across the UK vehicle fleet.

6.9 The demand for liquid fuel would be greatly reduced in this scenario. This demand could potentially be fully met by biofuels, which, by 2050, may be available with minimal life-cycle emissions. Since vehicles would be substantially less polluting, the scope for gains from efficient driving would be reduced, although choice of vehicle would remain significant.

6.10 The overall effect of this progress could be to reduce total CO_2 from road transport by 90 per cent per kilometre. Given potential increases in demand for road transport, total CO_2 emissions in 2050 could be around 80 per cent below current levels. This is achievable, but very challenging, and highly dependent on the development of advanced vehicle technologies and the generation of low-CO_2 electricity or hydrogen. To summarise:

- clean-powered vehicles – up to 80 per cent per kilometre emissions reduction for UK vehicle fleet;
- biofuels – 10 per cent CO_2 savings (higher if less is achieved through clean-powered vehicles); and
- consumer choices – choice of vehicle will be significant.

Strong early action is needed in all areas

6.11 As the above pathway illustrates, significant cuts in CO_2 from car use will require major changes in fuel technologies, vehicle technologies and consumer behaviour. There is an urgency to making progress in these areas since, as the Stern Review highlighted, CO_2 emissions avoided now are more valuable than those saved later. Moreover, the relatively long timescales involved in R&D, building vehicle and fuel production infrastructure, and fleet replacement mean that action is required now to realise major CO_2 savings by 2050. Strong early action could also provide economic benefits, allowing the UK to become market leaders in low-carbon fuel and vehicle technologies. In addition to the above, public transport provision and road pricing offer potential to moderate demand in a manner that is efficient and consistent with mobility and economic objectives.

Efforts from industry, consumers, and Government are needed

6.12 The push to decarbonise road transport will require major efforts from the automotive industry, the fuels sector, and individuals. On top of this, the move towards low-CO_2 alternative fuels will require major input from the power and agriculture sectors. There is also an important role for governments at all levels and in all countries who have the potential, through a wide range of policy levers, to address market failures and to influence the move to a prosperous, low-CO_2 economy.

6.13 UK Government is well-placed to take an international leadership role in reducing emissions from road transport. Through sound policies it can demonstrate to others that strong economic growth and environmental responsibility can be achieved together. By leading international negotiations, it can also ensure that other countries take steps to reduce their emissions and that progress is made on meeting the international policy challenges.

7 Conclusions and next steps

The challenge for road transport

7.1 The Stern Review sets out the context of the environmental challenge. Globally, a CO_2 reduction in greenhouse gas emissions of 25 per cent by 2050 is needed to reduce the risk of severe climate change. Action now, on a global scale, is an economic imperative.

7.2 The developed world needs to reduce its emissions by 60-80 per cent by 2050 and the UK is looking to lead the way across all sectors. In road transport, with demand for travel likely to increase, it will be important to achieve substantial savings from improvements in efficiency. This needs to come from cleaner fuels, improved vehicle technologies and smarter consumer choices.

7.3 By 2030, with action now, per-kilometre emissions could be reduced by 50 per cent, equivalent to a 30 per cent reduction in the absolute level of emissions. In the longer term, per-kilometre emissions of up to 90 per cent could be feasible with major vehicle technology developments and clean power.

Fuel technologies

7.4 Chapter 3 highlighted the importance of considering fuels based on CO_2 emissions throughout the life cycle. For different fuels, CO_2 is emitted at different stages of the production process and even for a single fuel type, CO_2 can vary significantly depending on how that fuel is sourced.

7.5 Biofuels, in moderation, offer potential advantages and can occupy a slice of the transport fuels market. But an over-reliance on biofuels, particularly in these early stages, poses large potential risks in terms of land use and biodiversity. Globally, care needs to be taken not to over-expand biofuels demand before technological improvements and comprehensive sustainability safeguards are in place.

7.6 **The King Review Part II will make recommendations on how to take account of CO_2 emissions across the life cycle in monitoring and incentivising fuels. This will include further analysis of biofuels and how they can be developed sustainably, as well as impacts for the UK.**

7.7 Chapter 3 also discussed how countries' road transport CO_2 emissions will increasingly be determined by the composition of the power generation sector. Major changes in power generation will need to be delivered alongside automotive technologies in order to move towards decarbonised road transport. Making progress on decarbonising power generation represents an even more urgent challenge than electric vehicle technologies because of the time it takes to implement. The King Review team will continue to work with Government Departments to identify the implications of road transport for the Government's wider energy strategy.

Vehicle technologies

7.8 Vehicle technologies that can deliver 30 per cent reductions in CO_2, and pay for themselves through fuel economy over the life of the vehicle, could be available in 5-10 years but demand and supply side factors are delaying their deployment.

7.9 **The King Review Part II will make recommendations on how close-to-market vehicle technologies might be brought into widespread use and their benefits realised as early as possible, while taking account of the interests of industry and consumers.**

7.10 By 2030, hybrid technologies are likely to be commonplace and average per kilometre emissions (across all vehicles) could be 30 per cent lower, subject to some, relatively low-risk, technological progress. Over the longer term, more substantial reductions in CO_2 emissions are likely to depend on the prevalence of electric or hydrogen vehicles, operated using clean power. Overcoming the vehicle technology challenges (particularly in respect of batteries and/or hydrogen production, storage and distribution) needed to achieve this, will require an effective programme of long-term research by the automotive and fuel industries.

7.11 **The King Review Part II will look in more detail at the research and development of automotive and fuel technologies and consider what further role the Government can play in supporting new technological developments in this area.**

Consumer choices

7.12 Consumers' decisions are fundamental to whether low-carbon technologies are adopted. Through the choices they make, both in purchasing and using their cars, consumers can have a significant impact on CO_2 emissions. The Review estimates that CO_2 savings of 15 per cent by 2030 can come from consumer choices, with many of these emissions reductions coming much sooner. Consumers would also stand to benefit from these choices, through improved fuel efficiency and lower fuel costs.

7.13 However, there are challenges to realising these savings. Environmental concern is not always reflected in consumer actions, especially in car purchasing decisions, and people tend to discount heavily the fuel savings from lower-carbon choices.

7.14 **The King Review Part II will make recommendations on how to realise more of the potential for CO_2 savings from consumer choices.**

A Acknowledgements

CALL FOR EVIDENCE CONTRIBUTORS

The King Review Team would like to thank everyone who responded to the Call for Evidence. We received almost 100 submissions, containing a wealth of interesting evidence and insights to inform the Review.

We have endeavoured to ensure that all individuals and organisations that have made representations to the King Review's Call for Evidence are included below, except those who requested anonymity. If we have made an inadvertent omission from this list, please accept our apologies.

Submissions received from members of the public:

Stephen Harding
Paul Kenny
Deborah King
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Nicholas Morgan
Ian MacPherson
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Stephen Plowden & Simon Lister
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Submissions received from organisations:

Alliance Against Urban 4x4s
ARUP
Association of British Drivers
Biomethane for Transport
BP
Bryte Energy Ltd
BVRLA
Calor Gas Limited
Carillion plc
Carplus
Cenex
Centre for Narrow Vehicle Research
Centre for Process Innovation Ltd
CSEM-BMP
Dragonfly Hybrids Ltd
Energy Saving Trust
Environmental Industries Commission
E.On

Faraday Advance
Food & Drink Federation
Ford Motor Company
Friends of the Earth
Fuel Cell Today
General Motors UK & Ireland
Geotech Resources Ltd
Greater London Authority
Greenpeace
Green Plus Ltd
GreenSpeed
Imperial College
Institution of Mechanical Engineers
ITM Power plc
Lancaster University
Lotus Engineering
Low Carbon & Fuel Cell Technology Knowledge Transfer Network
LP Gas Association
Lyondell Chemical Europe
Microcab Industries Ltd
The Narrow Car Company
National Physical Laboratory
National Transport Roundtable
Natural England
Natural Gas Vehicle Association
NICE Car Company
Oxfam
Oxonica
Provecta Car Plan Ltd
RAC Foundation for Motoring Ltd
Research Councils UK
Ricardo UK Ltd
Royal Society for the Protection of Birds
Royal Society of Chemistry
Shell International Ltd
The Business Project Office
The Greenfuel Company Ltd
The Hardstaff Group
The Slower Speeds Initiative
The Society of Motor Manufacturers & Traders
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National Non-Food Crops Centre
Office of Climate Change
Smith Electric Vehicles
Toyota
Transport for London
Virgin Fuels
Volvo
UK Petroleum Industries Association
Zytek

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