Chapter 4: Decarbonising surface transport

Introduction

Surface transport currently accounts for around 19% of total UK GHG emissions, and 22% of CO₂ emissions. By 2020, there is scope to reduce emissions by around 26% relative to 2008 levels through lower carbon vehicles (including electric vehicles), increased penetration of sustainable biofuels and behaviour change. These measures are in our Extended Ambition scenario to meet the first three carbon budgets and to prepare for meeting subsequent budgets.

In this chapter we consider scope for further cuts in transport emissions in the 2020s through improved efficiency of conventional vehicles, increased penetration of electric vehicles (battery electric, plug-in hybrid and potentially hydrogen fuel cell vehicles), biofuels, behaviour change, freight efficiency improvement and electrification of rail. We develop scenarios for each of the key technologies through the 2020s based on an assessment of feasibility and cost. These are then incorporated in the economy wide scenarios that underpin our advice on the fourth carbon budget.

The key messages in the chapter are:

• Under our Medium Abatement scenario surface transport emissions reduction of around 44% relative to 2008 levels is achieved by 2030.
  – Given scope for battery cost reduction and a rising carbon price, we envisage that battery electric and plug-in hybrid electric cars and vans will become cost-effective during the 2020s. This will provide scope for 60% electric vehicle penetration in new cars and vans by 2030.
  – There is scope to reduce conventional vehicle average tailpipe emissions between 2020 and 2030 by around 30% for new cars, and around 25% for new vans and HGVs. Building on improvements made in the 2010s this would result in average new car emissions of 80 gCO₂/km and average new van emissions of 120gCO₂/km in 2030.
  – Given current uncertainties over technologies for advanced biofuels and availability of land for growth of feedstocks, we limit take up of biofuels in the 2020s to the level suggested in the Gallagher Review for 2020 (i.e. around 2.7 million tonnes of oil equivalent, or 31.2 TWh).
  – There is scope for emissions reduction through the 2020s through improved efficiency of freight operations.
  – There may be significant scope for emissions reduction electrification of rail. However, further evidence is required to better understand this opportunity.
  – The cost associated with this emissions reduction is around 0.1% of GDP in 2030, mainly due to the cost of battery electric and plug-in hybrids cars.

1. Reference emissions projections
2. Scope for further improvements in conventional vehicle efficiency
3. Scaling up electric vehicle and plug-in hybrid penetration
4. Scope for increased use of biofuels
5. Opportunities for use of hydrogen in vehicles
6. Ongoing role for demand-side emissions reduction
7. The role for decarbonised rail
8. The role of freight operations and logistics
9. Surface transport emissions scenarios for the 2020s
10. Implications for first three budget periods
11. Key findings
• The Medium Abatement scenario is one possible path to delivering this level of abatement in surface transport. Depending on the pace of technology innovation, it is possible that other technologies (e.g. hydrogen vehicles) could contribute to the emissions reduction in this scenario, or deliver additional emissions reduction.

• In order to prepare for deep cuts in transport emissions through the 2020s, it is vital that support for electric vehicle market development is provided in the next few years. In the spending review the Government announced £400 million funding to promote the take up of ultra-low carbon vehicle technologies, including electric vehicles. Whilst this is a useful start, more resource is likely to be required to deliver the penetration of electric vehicles set out in our scenarios.

The analysis that underpins these conclusions is set out in ten sections:

1. Reference emissions projections
2. Scope for further improvements in conventional vehicle efficiency
3. Scaling up electric vehicle and plug-in hybrid penetration
4. Scope for increased use of biofuels
5. Opportunities for use of hydrogen in vehicles
6. Ongoing role for demand-side emissions reduction
7. The role of decarbonised rail travel
8. The role of freight operations and logistics
9. Surface transport emissions scenarios for the 2020s
10. Implications for the first three budget periods

1. Reference emissions projections

Current emissions

Surface transport CO₂ emissions¹ in 2008 were 119 MtCO₂, accounting for around 22% of economy-wide CO₂ emissions and around 19% of greenhouse gas emissions (Figure 4.1). Cars account for around 60% of surface transport CO₂ emissions, with vans accounting for 13% and HGVs for 20% (Figure 4.2).

The recession contributed to reduced transport emissions in 2008 and 2009. However, total surface transport emissions have increased significantly since 1990 with improvements in vehicle fuel efficiency more than offset by increased miles travelled.

¹ Unless otherwise indicated, this chapter refers to the direct emissions of transport throughout. Emissions associated with power generation or refineries are covered in the chapters related to Power generation and Industry.
• Total surface transport emissions increased by 7% between 1990 and 2008. This was due to:
  – Between 1990 and 2008 emissions intensity of cars fell by 16% from 205 gCO₂/km to 173 gCO₂/km, whilst distance travelled increased by 20% from 350 billion km to 418 billion km (Figure 4.3).
  – Between 1990 and 2008 emissions intensity of vans fell by 3% from 233 gCO₂/km to 226 gCO₂/km, whilst distance travelled increased by 71% from 41 billion km to 69 billion km (Figure 4.4).
  – Between 1990 and 2008 emissions intensity of HGVs fell by 14% from 917 gCO₂/km to 791 gCO₂/km, whilst distance travelled increased by 15% from 26 billion km to 30 billion km (Figure 4.5).
• Total surface transport emissions decreased by 1.7% in the period from 2004-2008. In 2008 road transport emissions fell by 3.5% with a preliminary estimate of a further 3.9% reduction in 2009. Emissions reduction in 2008 and 2009 were due to the purchase of more efficient vehicles, increased penetration of biofuels and reduced mileage.

**Emissions projections to 2020**

We have previously defined Extended and Stretch Ambition scenarios for transport, including both technology and behaviour change measures for emissions reduction, and covering the first three budget periods:

- The **Extended Ambition** scenario includes a range of measures relating to the uptake of technologies and behavioural change. The majority of these measures are either negative cost (i.e. cost saving) or cost-effective compared to the UK carbon price over this period.

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**Figure 4.3:** Historical trends of vehicle km, MtCO₂ and gCO₂/km for cars (1990-2008)

**Figure 4.4:** Historical trends of vehicle km, MtCO₂ and gCO₂/km for vans (1990-2008)

**Figure 4.5:** Historical trends of vehicle km, MtCO₂ and gCO₂/km for HGVs (1990-2008)
The remainder (electric and plug-in hybrid vehicles) would bring to market technologies that will be required to meet the 2050 target and are likely to be cost-effective in meeting carbon budgets through the 2020s. Key measures in the Extended Ambition scenario are (Figure 4.6):

- **New car efficiency of 95 gCO₂/km in 2020.** New car CO₂ emissions in the UK should decrease from around 150 gCO₂/km in 2009 to the EU target levels of 130 gCO₂/km in 2015 and 95 gCO₂/km in 2020. This can be achieved by a range of feasible and cost-effective measures to improve engine efficiency and non-powertrain measures. We allow electric vehicles to contribute to meeting this limit. Excluding these, conventional car efficiency is 110 gCO₂/km by 2020.

- **Battery electric and plug-in hybrid car penetration of up to 1.7 million in 2020.** The introduction of battery electric and plug-in hybrid cars is technically feasible, and desirable given that this technology is the most promising for the deep emissions cuts required in transport through the 2020s. We have recommended that by 2020 around 5% of all cars and 16% of new cars should be battery electric and plug-in hybrid in order to address market barriers and provide critical mass for roll-out in the 2020s.

- **New van efficiency of 135 gCO₂/km in 2020** in line with the proposed EU target, to be achieved by a combination of more efficient conventional vans, and battery electric and plug-in hybrid vans

- **HGVs.** Uptake of non-powertrain technologies and the introduction of hybrid rigid HGVs could reduce emissions by 0.6 MtCO₂ in 2020.

- **Biofuels penetration of 8% in 2020.** Increased penetration of biofuels up to 8% of total liquid fuel consumption (by energy) would be consistent with broader sustainability limits, as recommended by the Gallagher review.

- **Roll-out of Smarter Choices to all UK cities and towns.** Evidence from the Sustainable Travel Town pilot projects suggests that people respond to policies encouraging car sharing, working from home and use of public transport (e.g. resulting in a reduction in car km of around 5-7%).

- **Take up of eco-driving.** Training 10% of car and van drivers and 100% of HGV drivers in eco-driving techniques (e.g. gentle braking and accelerating, not driving with excess weight, etc.) could result in an emissions reduction of 0.9 MtCO₂ in 2020.

- **Enforcing the speed limit.** If the existing 70 mph speed limit were strictly enforced, this could reduce emissions by 1.3 MtCO₂ in 2020.

- **The Stretch Ambition scenario includes measures which are likely to be cost-effective in reducing emissions, but where political considerations may pose a more significant barrier.** Key measures in the Stretch Ambition scenario are:

  - **Introduction of road pricing.** If introduced in addition to existing fuel duty, rather than as an alternative, this would result in significant emissions reduction (e.g. 5.6 MtCO₂ in 2020) due principally to a reduction in total distance travelled.

  - **Reduction of the speed limit.** Significant fuel efficiency improvements and emissions reduction (around 1.5 MtCO₂ in 2020) are available through reducing the existing 70 mph speed limit to 60 mph.
Our analysis suggests that an emissions reduction of around 26 MtCO2 is available in 2020 from 2020 to 2030 (Box 4.1). Travel distance increases by 9%, van distance by 24% and HGV distance by 5% in the period changing fossil fuel prices, economic growth and changing demographics. It projects that car emissions under the Extended Ambition scenario, with an additional 7 MtCO2 emissions reduction under conventional car efficiency remains at 110 gCO2/km, electric car penetration is 16% of new cars). If the Extended Ambition is delivered then surface transport emissions in 2020 would be around 89 MtCO2. This would be high relative to total allowed emissions of 160 MtCO2e in 2050, the Stretch Ambition scenario.

Reference emissions projections for the 2020s

In developing reference emissions projections for the 2020s, we assume that emissions reduction effort remains constant at levels in the Extended Ambition scenario (e.g. conventional car efficiency remains at 110 gCO2/km, electric car penetration is 16% of new cars).

We use travel demand projections from DfT’s National Transport Model. This allows for changing fossil fuel prices, economic growth and changing demographics. It projects that car travel distance increases by 9%, van distance by 24% and HGV distance by 5% in the period from 2020 to 2030 (Box 4.1).

Combining the assumptions on carbon intensity (Figure 4.8) and the travel demand projections gives a reference emissions projection under which surface transport emissions decrease by around 8% in the period to 2030. This defines a benchmark, against which we now consider opportunities to reduce emissions through the 2020s.

**Box 4.1: National Transport Model projections**

The National Transport model forecasts total road traffic and emissions for cars, vans, HGVs and public service vehicles (buses and coaches) in Great Britain. Our reference emissions projection is based on National Transport Model forecasts of total road traffic which are consistent with the following assumptions:

- The number of households in Great Britain is forecast to rise from 26.0 million in 2010 to 31.5 million in 2030, according to DfT’s Trip End Model Presentation Program (TEMPRO).
- The total number of cars in Great Britain is forecast to rise from 28.5 million in 2010 to 36.4 million in 2030 (an increase in car ownership from 1.10 cars per household in 2010 to 1.16 in 2030), according to DfT’s Car Ownership Model based on TEMPRO data.
- GDP is forecast to increase by 62% between 2010 and 2030. This is based on the forecast for the next five years of GDP growth published by the Office of Budget Responsibility in the June 2010 Budget and forecasts of subsequent GDP growth from HMT’s long-term forecasts.
- Petrol prices are forecast to rise from 100 pence per litre in 2010 to 128 pence per litre in 2030, while diesel prices are forecast to rise from 115 pence per litre in 2010 to 131 pence per litre in 2030. These prices are based on the DECC/DfT road fuel price forecasting model using DECC’s oil price projections, oil prices are forecast to rise from $72/bbl in 2010 to $92/bbl in 2030.

We adjust the National Transport model forecast figures to account for traffic in Northern Ireland. With these assumptions, total road traffic is forecast to rise from 409 billion vehicle-km in 2010 to 446 billion in 2020 and 485 billion in 2030 for cars; and 72 billion vehicle-km in 2010 to 92 billion in 2020 and 114 billion in 2030 for vans; and 30 billion vehicle-km in 2010 to 32 billion in 2020 and 33 billion in 2030 for HGVs; and 5 billion vehicle-km between 2010 and 2030 for public service vehicles.

2. Scope for further improvements in conventional vehicle efficiency

If the EU target for new car emissions and the proposed target for new van emissions are achieved in the UK in 2020, in part through the contribution of electric and plug-in hybrid cars and vans set out in our Extended Ambition scenario, the implication is that conventional car emissions would be around 110 gCO2/km, and conventional van emissions around 150 gCO2/km.

Going beyond 2020, it is likely that there will be further scope for fuel efficiency improvement in conventional cars, vans, and HGVs, for example, through increased hybridisation, downsizing of engines with turbocharging and use of advanced light weight materials.

Although there is uncertainty over precisely how far efficiencies can be improved, there is strong evidence to suggest that conventional car emissions could be reduced to at least 80 gCO2/km by 2030 (while some industry participants suggest a level as low as 60 g/km), with van emissions falling to 120 gCO2/km, and HGV emissions falling to 415-705 gCO2/km depending on size.
In modelling our Medium Abatement scenario for surface transport, we assume conventional car efficiency of 80 g/km and conventional van efficiency of 120 gCO₂/km in 2030, and a 15-30% efficiency improvement between 2020 and 2030 for HGVs (Box 4.2). In modelling our High Abatement scenario we assume a conventional car efficiency of 70 gCO₂/km, reflecting more optimistic assumptions on the efficiency improvement that can be achieved cost-effectively.

These efficiency improvements could potentially make a useful contribution to meeting the fourth and subsequent carbon budgets. However, there is a limit to how far the efficiency of conventional vehicles can be improved, and new technologies will be required to achieve deep cuts in transport emissions. We now consider these new technologies, starting with electric vehicles, then biofuels and hydrogen.

Box 4.2: Reduction in conventional vehicle CO₂ emissions

We have based our assumptions on the efficiency of new conventional vehicles (vehicles powered principally by an internal combustion engine, including hybrid but not plug-in hybrid vehicles) on two main sources:

- a study by AEA for the European Commission for cars and vans⁷
- a study by Ricardo for the Department for Transport for Heavy Goods Vehicles (HGVs)⁸

The AEA study was produced to inform development of the European Commission’s proposals for long-term targets as part of the regulation of the CO₂ emissions from new passenger cars and light commercial vehicles. The study evaluated the technical potential of achieving a range of new car and van CO₂ targets, and the expected costs of doing so. The study concluded that targets of 85 gCO₂/km in passenger cars and of 125 gCO₂/km in light commercial vehicles are achievable by 2030 with the application of either extra strong downsizing with turbo charging; or full hybridisation, as well as a range of additional technologies to further reduce emissions.

AEA note that although unlikely to be a feasible and economically viable option for the 2020 time frame, from a technical point of view extra strong downsizing with turbo charging and full hybridisation can in principle be combined. Given AEA’s conclusion that 85 g CO₂/km in passenger cars and 125 g CO₂/km in light commercial vehicles are achievable by 2030 with the application of one or other technology, we considered that CO₂ emissions consistent with the combination of both technologies would be an appropriate target level for vehicles in 2030. We have therefore assumed that

- new conventional car CO₂ would decline from around 110 gCO₂/km in 2020 to around 80 gCO₂/km in 2030
- new conventional van CO₂ would decline from around 150 gCO₂/km in 2020 to around 120 gCO₂/km in 2030.

The Ricardo study was produced to inform future UK Government policy on reducing emissions from HGVs. The study identified a range of technologies with potential to reduce emissions from different categories of HGV as well as their likely costs. Further work is required to determine the likely optimal combination of these technologies and the emissions reduction resulting from combining several technologies. We have therefore taken a conservative approach and selected a small number of technologies to apply to each class of HGV.

This reduces emissions from the Extended Ambition scenario

- from 500 gCO₂/km in 2020 to 415 in 2030 for small rigid HGVs (a 17% reduction)
- from 845 gCO₂/km in 2020 to 705 in 2030 for large rigid HGVs (a 17% reduction)
- from 775 gCO₂/km in 2020 to 555 in 2030 for small articulated HGVs (a 28% reduction)
- from 880 gCO₂/km in 2020 to 640 in 2030 for large articulated HGVs (a 27% reduction)

3. Scaling up electric vehicle and plug-in hybrid penetration

Battery electric and plug-in hybrid electric vehicles are very promising options for cutting transport emissions in the 2020s given the need to decarbonise power generation. The pace and scale of roll-out of these vehicles will depend on battery cost reductions and range increases; where there is more battery cost reduction and where range is longer, there is greater scope for electric vehicle penetration.

In this section we:

- Set out scenarios for electric vehicle penetration through the 2020s reflecting different assumptions about battery cost and public acceptance.
- Assess the cost of delivering these scenarios.
- Consider implications of increased penetration of electric vehicles for the power system (generation and networks).

We set out our analysis in four sections:

i. Scenarios for electric and plug-in hybrid cars
ii. Scenarios for electric and plug-in hybrid vans

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⁷ AEA, CE Delft, TNO et al (2009), Assessment with respect to long term CO₂ emission targets for passenger cars and vans.
⁸ Ricardo (2010), Technology Roadmap Study for Low Carbon HGVs.
iii. Implications for the electricity system

iv. The rationale for an early stage market in electric and plug-in hybrid vehicles

We do not consider the scope for electric HGVs. We recognise that a number of small electric HGVs are available today and that wider uptake could provide a valuable opportunity to reduce emissions in the city delivery vehicle segment of the HGV market. However, the majority of HGVs have much larger range requirements than cars (e.g. small rigid HGVs have annual mileage 170% greater than cars and large articulated HGVs have mileage over 600% greater). Therefore, the scope for widespread deployment of electric HGVs is likely to be limited, with emissions reduction more likely to ensue from biofuels and hydrogen (see sections 4 and 5 below).

(i) Scenarios for electric and plug-in hybrid cars

Electric vehicle purchase to 2020

Under our Extended Ambition scenario electric and plug-in hybrid cars account for 16% of new cars and around 5% of the car fleet by 2020. This scenario reflects market developments to address barriers and provide a critical mass for roll-out in the 2020s. It is based on analysis that shows electric and plug-in hybrid cars are likely to be attractive in terms of performance characteristics and to become cost-competitive with conventional cars:

- **Range.** The performance characteristics of electric cars will allow them to compete with conventional cars. Analysis by Element Energy indicates that 96% of car trips and 73% of total car distance travelled are covered by individuals driving no more than 100 miles in a single day – the range of current batteries (Figure 4.9). Whilst battery ranges are likely to improve, options for situations where a battery range of 100 miles is insufficient are:
  - Switching longer trips to a conventional car in two-car households.
  - Renting conventional cars for longer journeys, or using alternative modes of transport.
  - A widespread national fast charging infrastructure to reduce the effective range limitations of battery electric vehicles.
  - Use of plug-in hybrid vehicles.

- **Cost.** The economics of electric vehicles are such that these will be competitive with conventional cars under an assumption that existing fuel duty remains, and following a transitional period where electric battery costs fall as a result of learning through deployment (see below).

Scenarios for electric car deployment through the 2020s

Given sufficient progress in the period to 2020, there will be the option to roll out electric cars in the 2020s. Key drivers on the pace and scale of roll-out will be battery cost reductions and range increases (e.g. penetration is likely to be higher the more that battery costs are reduced and/or range is increased). Therefore our scenarios for roll-out in the 2020s reflect different assumptions on battery costs and range:

- **Low scenario.** This assumes no increase in market share of electric cars beyond 2020. These continue to account for around 16% of new cars, and around 15% of the fleet in 2030. Limited uptake could reflect a world where electric cars are overtaken by other options for cutting car emissions (e.g. because battery costs fail to fall and/or there are breakthroughs that bring abundant and low-cost sustainable biofuels to market). Alternatively, limited uptake could result if the public failed to embrace electric cars (e.g. because these were perceived as being deficient in terms of performance).

- **Medium scenario.** Under this scenario take-up of electric cars reaches 60% of new vehicles (31% of the fleet) in 2030, of which 30% are battery electric and the remaining 70% are plug-in hybrid cars. This outcome reflects the following assumptions:
  - Battery costs fall to around $200/kWh by 2030 (Box 4.3), with no change in assumed range.
  - Battery electric cars replace conventional vehicles that are rarely or never used for long-range trips – 85% of cars do not drive more than 100 miles within the average week, and 73% of car drivers undertake a long distance trip (greater than 50 miles) less than once a month.
  - Battery electric cars replace conventional vehicles in multi-car households (30% of all households) that sometimes make long-range trips; in this case longer trips are switched to the household’s conventional car.
  - Consumers requiring significant range purchase plug-in hybrid cars which do not have range constraints and can therefore perform as well as conventional cars.

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**Figure 4.9:** EV and PHEV range

![Graph showing EV and PHEV range](source: Element Energy analysis based on the National Travel Survey (2009).)
Electric car costs: social perspective

The electric car costs in the above scenarios can be justified on two grounds:

- The cost per tonne of CO₂ abated from electric cars is less than the carbon price in 2030. The relevant carbon price here is the average over the life of an electric car, which we project to be around £65/CO₂ for a car purchased in 2020, rising to £103/CO₂ for a car purchased in 2030 (see Chapter 2 for our carbon price projections).

- 100% electric car penetration in the fleet is required by 2050 to meet the 2050 emissions reduction target. Given the delays caused by fleet rollover early deployment of electric vehicles is required, even though this may initially cost more than the carbon price, to ensure that electric vehicles deliver the required amount of abatement in 2050.

In considering electric car costs versus conventional alternatives, two factors are relevant:

- The purchase costs of electric cars are relatively high compared to conventional alternatives, primarily due to battery costs; current battery costs of under $1000/kWh are expected to fall to $285/kWh by 2020, with further reductions to as low as $200/kWh by 2030 (Box 4.3).

- Electric cars are cheaper to run than conventional cars, given their significantly greater efficiency. We estimate a cost differential of around 1.6-2.5 pence/km depending on assumptions about electricity costs (Box 4.4).

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Figure 4.10: Emissions reductions in 2030 from battery electric and plug-in hybrid cars in Medium and High abatement scenarios

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Medium</th>
<th>High</th>
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</thead>
<tbody>
<tr>
<td>BEV</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>PHEV</td>
<td>81</td>
<td></td>
</tr>
</tbody>
</table>

High scenario. Under this scenario take up of electric cars reaches 85% of new vehicles (37% of the fleet) in 2030. Of these, 70% are battery electric and the remaining 30% are plug-in hybrid cars. This outcome reflects the following assumptions:

- Battery costs are significantly lower than our central estimate of $200/kWh, such that it is cost-effective to deploy battery electric cars with significantly greater range than 100 miles; or
- A degree of behaviour change such that drivers motivated to purchase an electric vehicle due to the operating cost savings switch to public transport or use car clubs for long distance trips, or seek alternatives to travel.

Electric car emissions reduction

Emissions reduction from electric car penetration depend on the carbon intensity of power used for battery charging. For example, charging based on gas-fired power generation offers limited saving relative to a conventional engine with emissions of 80 gCO₂/km. In contrast, electric cars may be regarded as zero- or very low-carbon when charging is based on low-carbon generation (i.e. nuclear, CCS, renewable – see Chapter 6).

Provided that charging is based on low-carbon generation, the emissions reduction in the Medium scenario compared with the reference emissions projection is 78 MtCO₂ in 2030, rising to 14.1 MtCO₂ in the High scenario (Figure 4.10). By 2030 average car fleet emissions in the Medium scenario are around 81 gCO₂/km.

Box 4.3: Electric vehicle battery costs

There is no accepted, reliable source of data on past and current prices for electric vehicle batteries. Previous studies have reported estimates of battery costs of around $1,000 (at time of publication), although anecdotal evidence suggests that current purchase prices at volume are significantly lower than this.

A number of studies have estimated prospects for near-term cost reduction. For example, Argonne National Laboratories (2008) estimate an ‘optimistic future’ cost of $250/kWh, while more recent estimates include California Air Resources Board’s (2007) future cost estimate of $342-$475 and Boston Consulting Group’s (2010) estimate of $360-$440.

Such prospects for near-term reduction and likely stronger prospects for longer term reduction are reflected in a number of industry targets. For example:

- EUROBAT (the trade organization for European manufacturers of storage batteries) has a current objective for cost reduction in Li-ion battery packs of €200 ($246).
- The United States Advanced Battery Consortium (USABC), a subsidiary of the United States Council for Automotive Research (an organization comprising Chrysler Group, Ford Motor Company and General Motors Company) has defined a ‘minimum goal for commercialization’ of $150/kWh and a long-term goal of $100/kWh.
- The Japanese Ministry of Economy, Trade and Industry (METI) has announced a target cost of 5% of 2010 levels, which equates to around $50/kWh.

Following our 2009 report, we continue to use our working assumption that costs will fall to $285/kWh in 2020. We reflect the scope for continued cost reductions, as indicated by the manufacturer targets above, in a cost of $200/kWh by 2030.

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Table 3.2: Electricity cost differentials over the life of an electric car

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Battery electric</th>
<th>Plug-in hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td>High</td>
<td>1.6</td>
<td>2.5</td>
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</table>
Box 4.4: Operating costs of electric and conventional vehicles

The Department for Energy and Climate Change (DECC) forecast that the variable cost of petrol (i.e. the resource cost net of fuel duty) will be around 44 p/litre in 2030. With 35 MJ of energy per litre of petrol, this equates to 1.3 p/MJ. DECC also forecast that the variable cost of electricity will be 14 p/kWh in 2030, or 4 p/MJ. However, in our Medium power sector scenario (Chapter 3), 80 GW of total installed nameplate low-carbon capacity by 2030 would result in a variable cost of off-peak electricity of 2.7 p/kWh, or 0.8 p/MJ (around half the cost of petrol on an energy basis).

In addition to the lower cost of electricity in our Medium power sector scenario, electric vehicles are significantly more efficient than internal combustion engine vehicles. AEA (2008) estimate that the energy consumption of a conventional medium-sized petrol car is 2.4 MJ/km, whereas that of the equivalent electric car is 0.7 MJ/km.

Taking account the forecast costs of petrol and electricity and the relative fuel efficiency of petrol and electric cars, we estimate the energy costs of a conventional petrol car to be around 3.1 p/km, and those of an electric car to be around 0.5 p/km in 2030.

An efficient conventional (e.g. hybrid) petrol car in 2020 that achieves 95 g/km in line with the EU target would have an energy consumption of 1.4 MJ/km and an energy cost of 1.8 p/km, while a car achieving 80 g/km would have an energy consumption of 1.2 MJ/km and a cost of 1.5 p/km – such cars would still not be as efficient or as cheap to run as an electric car with today’s technology.

Our assessment is that electric car and plug-in hybrid cars are cost-effective relative to our projected carbon price in 2030 across a range of sensitivities, with significant penetration in 2030 required on the path to meeting the 2050 target:

- We estimate a range of abatement costs from -£63 to £73/tCO2 for battery electric cars and -£9 to £127/tCO2 for plug-in hybrid cars depending on assumptions about battery costs, electricity prices and fossil fuel prices (Box 4.5); our central estimate of £26/tCO2 (battery electric car) and £80/tCO2 (plug-in hybrid electric car) is less than the average carbon price over the lifetime of a car bought in 2030 of £103/tCO2.

- All cars are likely to have to be electric (battery electric, plug-in hybrid or hydrogen fuel cell) by 2050 in order to meet the 80% reduction target. Given an average twelve to thirteen year stock turnover, the implication is that almost all new cars will have to be electric by 2035. In turn, this implies the need for significant penetration by 2030, given limits on scope for accelerating the pace of take-up.

Applying these abatement cost estimates to the Medium scenario suggests a total cost of around 0.06% of GDP in 2030, with a range from -0.01% to 0.1% of GDP depending on assumptions about battery costs and fossil fuel prices.

### Electric car costs: private perspective

Although the analysis above justifies our scenarios from an economic perspective, divergence between social and private costs raises a question about whether these will ensue in practice:

- Social costs are calculated using a social discount rate of 3.5% as recommended by the HMT Green Book, and fuel duty is netted out of petrol and diesel prices.

- Private costs are those faced by the consumer, reflecting a higher discount rate and including fuel duty; the former increases and the latter reduces the relative cost of electric cars.

There is evidence to suggest that consumers can be myopic and use very high discount rates (e.g. 25%), which may be prohibitive for the purchase of electric cars (i.e. heavily discounted operating cost savings would be insufficient to cover battery costs). However, this possibility has been recognised by the industry, which is introducing innovative business models such as battery leasing to better align the time profile of costs and benefits from electric car purchase.

However our analysis suggests that electric cars are likely to be competitive with conventional alternatives for a discount rate of 7.5% and forecast fuel costs including fuel duty by 2020, and it is appropriate to aim to deliver significant electric car penetration through the 2020s.

(ii) Scenarios for electric and plug-in hybrid vans

#### Electric van scenarios

Our approach to electric van scenarios is similar to that for electric cars: we assume a 2020 penetration as defined under the Extended Ambition scenario (i.e. electric and plug-in hybrid vans account for 16% of new vans in 2020 and 5% of the fleet); we set out three scenarios reflecting different assumptions about battery costs and range, and tracking the electric car scenarios.

- **Low scenario.** There is no increase in market share of electric vans beyond 2020 (i.e. electric vans continue to account for 16% of new vans and reach a 14% share of the fleet by 2030).

- **Medium scenario.** This tracks the Medium scenario for electric cars, such that take up of electric vans reaches 60% of new vehicles (29% of the fleet) in 2030; given uncertainty over the extent to which van miles are within battery range, we assume a high proportion (87.5%) of plug-in hybrid vans in this scenario.

- **High scenario.** This tracks the High scenario for electric cars, such that electric vans account for 85% of new vans in 2030 and 39% of the van fleet. Given uncertainty over the extent to which van miles are within battery range, but allowing for improvements in range with battery cost reductions, in this scenario 50% of new electric vans are battery electric and the remaining 50% are plug-in hybrid vans.

Under an assumption of overnight charging from low-carbon generation, the emissions reduction in the Medium scenario compared with the reference emissions projection is 2.2 MtCO2 in 2030, rising to 4.8 MtCO2 in the High scenario (Figure 4.11). By 2030 average van fleet emissions in the Medium scenario are 118 gCO2/km.
### Electric van costs

As with electric cars, the economics of electric vans depend on battery costs, electricity costs and petrol/diesel prices. Our assessment is that electric vans are cost-effective compared to the carbon price across a range of sensitivities, with significant penetration required on the path to meeting the 2050 target:

- We estimate a range for battery electric van marginal costs of -£52 to £82/tCO₂ in 2030 and for plug-in hybrid vans of -£62 to £72/tCO₂ in 2030, relative to the average carbon price projected over the life of a van purchased in 2030 of around £103/tCO₂ (Box 4.5).
- If vans are to be fully decarbonised by 2050, this implies that almost all new vans purchased in 2035 are electric. Without significant uptake in 2030 (e.g. as in our Medium scenario), it is unlikely that such penetration would be plausible in 2035.

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### Box 4.5: PHEV and EV marginal costs

We estimate abatement costs in 2030 for electric vehicles as follows:

- £26/tCO₂ for BEV cars
- £80/tCO₂ for PHEV cars
- £37/tCO₂ for BEV vans
- £26/tCO₂ for PHEV vans

These abatement costs are based on the following assumptions:

- For cars, the comparator vehicle is a medium-sized conventional petrol car
- Battery costs fall to $200/kWh in 2030
- Fuel prices are consistent with DECC's central fuel price scenario
- Electricity costs are 2.7 p/kWh in 2030 based on overnight charging (Box 4.4)
- Fuel savings are discounted at 3.5%.

We have also performed sensitivity tests to determine the extent to which capital costs (i.e. battery costs) and fuel prices affect the abatement costs. Table B4.5 sets out our estimates of abatement costs under the following assumptions:

- Electricity costs reflect the long run marginal cost of nuclear generation.
- DECC’s lowest and highest fossil fuel price forecasts.
- A 25% decrease and 25% increase in battery costs.

<table>
<thead>
<tr>
<th>Assumption</th>
<th>BEV Cars</th>
<th>PHEV Cars</th>
<th>BEV Vans</th>
<th>PHEV Vans</th>
</tr>
</thead>
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<td>£80</td>
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<td>£82</td>
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</tr>
</tbody>
</table>

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### (iii) Implications for the electricity system

#### Power generation

The scenarios for electric vehicles above would create electricity demand of around 31 TWh per year (Medium scenario) and 51 TWh per year (High scenario). This would require capacity of around 12-20 GW per year of the 80 GW total installed nameplate low carbon capacity in 2030 in the Medium Abatement scenario (Chapter 6) (Box 4.6).
Charging during off peak periods (e.g. home charging overnight, daytime workplace charging) would minimise the requirement for additional power generation capacity. It would also allow utilisation of spare low-carbon capacity, and therefore maximise emissions reduction. This would require smart meters and time of day tariffs to signal the underlying economics to drivers.

We model this demand for electricity and capacity in our scenarios for development of the power sector (see Chapter 6).

**Box 4.6: Estimated electricity demand and capacity requirements**

Electricity demand from transport in the Low, Medium and High scenarios will arise from:

- BEV cars and vans
- PHEV cars and vans
- Hydrogen production for fuel cell vehicles

We estimate this electricity demand based on the following assumptions:

- 100% of BEV mileage is done in electric mode
- 30% of PHEV mileage is done in electric mode
- Total annual distance travelled is around 13,000 km per car and 27,000 km per van
- Energy consumption of BEV and PHEV (electric mode) is 0.72MJ/km for cars and 0.91MJ/km for vans

With the above assumptions, we estimate annual electricity demand from take up of BEV, PHEV and hydrogen fuel cell PHEV cars and vans in our Low, Medium and High scenarios as follows:

- **Low scenario**: 4.4 TWh in 2020 rising to 15 TWh in 2030
- **Medium scenario**: 4.4 TWh in 2020 rising to 30.6 TWh in 2030
- **High scenario**: 4.4 TWh in 2020 rising to 51 TWh in 2030

In order to estimate the required generation capacity we assume that overall charging will be spread equally throughout the year, and throughout a seven hour period each day. This would require:

- Low scenario: 1.7 GW in 2020 rising to 5.9 GW in 2030
- Medium scenario: 12 GW in 2030
- High scenario: 20 GW in 2030

**Power transmission and distribution**

In principle, there could be significant implications for investment in power transmission and distribution networks from the deployment of electric vehicles. In practice this will depend on the way consumers use their vehicle and different charging models (e.g. home charging versus battery exchange).

- With overnight home charging, batteries could be charged at a rate such that overnight demand would be no more than demand in the peak, and therefore require no extra network capacity. This would also be true of limited levels of slow charging at work during the day. In either case, this would require smart meters/a smart grid, which we consider further in Chapter 6.

- Any battery exchange would likely to involve a mix of overnight and peak charging depending upon the pattern of demand and the costs of holding spare batteries compared to the costs of recharging.

- Further network investment would be required for fast charging during peak periods. Our analysis suggests that there could be significant costs associated both with the installation of an extensive fast charging network, and with the further distribution network investment to support this (Box 4.7). However, it is not clear that an extensive fast charging network is required, and the costs of fast charging at lower levels are likely to be more manageable.

This reinforces the point that battery charging should be off-peak in order to minimise costs, which will require smart meters and time of day tariffs.

**Box 4.7: Cost associated with fast charging**

In our 2009 Progress Report we estimated that the total costs of an extensive infrastructure to support the roll-out of 1.7 million BEVs and PHEVs to 2020 might cost around £1.4 billion, comprising:

- dedicated slow-charging posts for the 25% of drivers who do not have off-street parking, at a cost of around £1 billion.
- charging posts in work-places for 5% of drivers, at £210 million.
- a total of 3,200 fast-charging points (i.e. two for every 1,000 electric cars) in public places, e.g. supermarkets, at a cost of £310 million.
- provision of four fast-charging points every 35 km in each direction on motorways and every 50 km on trunk roads, at £70 million.

(iv) The rationale for supporting an early stage market in electric and plug-in hybrid vehicles

It is important for the Government to provide support for the early market and to develop the electric vehicle option:

- By 2050 the entire car stock needs to be electric in order to meet the Climate Change Act’s 2050 emission reduction target. Given the lifetime of vehicles, this means that 100% of new cars in 2035 need to be electric (battery electric, plug-in hybrid or hydrogen fuel cell). This requires significant penetration by 2030 given limits on scope for accelerating the pace of take up. For example, delays in the pace of take up before 2035 require very rapid acceleration in rates of take up in the period to 2035 (Figure 4.12).

- Our analysis shows that electric vehicles will be cost-effective compared to the carbon price in the 2020s.

- Delay in the take-up of electric vehicles would require the Government to purchase credits in later years when these credits are likely to be in short supply and the carbon price is likely to be very high. We estimate that these costs could be substantial – over £5 billion in present values using the battery costs in our Medium scenario – even taking into account the higher technology costs incurred through earlier deployment (Box 4.8).
We estimate that the cost to the UK of delaying the introduction of electric vehicles by 5 years is over £5 billion in present values. This is much larger than the £800 million cost we estimated to support the roll-out of electric cars in line with our Extended Ambition scenario. Our analysis compares one scenario where 100% of the car stock is electric by 2050 with another which achieves 100% by 2055.

In the analysis:

• Both scenarios aim to deliver the same level of net abatement. Where electric vehicles are delayed the shortfall in abatement is made up with credit purchase.
• We use the carbon price set out in chapter 2 which reaches £200/tCO₂ by 2050.
• Abatement costs decline over time as batteries improve in cost and performance. This means that the delay scenario benefits from lower abatement costs from electric cars.
• All cash flows are discounted at 3.5% real, the Government’s social discount rate.

The figure below shows that the costs of delay are much higher than the costs of not delaying. Although the cost of electric vehicles is lower in the delay scenario – because the technology is more mature – the cost of credit purchases in later years more than offsets this.

We therefore restate our previous recommendations on transitional price support and investment in battery charging infrastructure:

• Transitional support should be provided for purchase of electric vehicles to cover the initial period where battery costs net of any operating cost savings are high.
• The Government should fund and facilitate investment in a network of battery charging points. This should initially be based on home charging overnight, both to utilise spare low-carbon generation capacity, and given the high cost of fast charging points in public places.

We estimate that required public funding would be around £800 million to cover purchase cost premiums, with further funding required depending on the extent of fast battery charging. In the spending review the Government announced £400 million for measures to promote the take up of ultra-low carbon technologies, including electric vehicles. Whilst this is a useful start, more resource is likely to be required to deliver the penetration of electric vehicles set out in our scenarios.
4. Scope for increased use of biofuels

Our Extended Ambition scenario assumes 8% penetration by energy of biofuels in 2020 in line with the Gallagher review recommendations. In this section we consider scope for increased penetration of biofuels in the 2020s subject to technical feasibility and sustainability constraints. We set out scenarios for penetration of biofuels to 2030, and assess the role for biofuels as a complement to other options for cutting transport emissions (e.g. plug-in hybrid vehicles). We also provide high-level estimates of costs associated with increasing biofuels penetration.

We now consider:

i. Feasibility and sustainability of biofuels

ii. Scenarios for biofuels penetration in the 2020s

iii. Possible roles for biofuels in road transport, emissions reduction and costs

(i) Feasibility and sustainability of biofuels

We have previously considered feasibility and sustainability constraints on increasing biofuels use in the context of our aviation review.

- **Feasibility.** It is likely that second generation biofuels will be available for use in the 2020s through a range of processes currently under development, although the precise timing and scale of availability remains uncertain:
  - hydrocracking vegetable oil and animal fats,
  - gasification of biomass combined with Fischer-Tropsch synthesis,
  - hydrothermal upgrading of biomass, where cellulosic materials are dissolved in water under high pressure and low temperatures to form a biocrude liquid, or
  - fast pyrolysis, in which biomass is heated rapidly in the absence of air and cools to a bio-oil.

However, the timing and order of magnitude of availability is currently uncertain, given need for innovation in feedstocks and processing plants and the investment required to produce at scale.

- **Lifecycle emissions reduction.** The extent to which biofuels can be regarded as zero carbon depends upon land-use impacts from growth of biofuels feedstocks and emissions from the production of biofuels. Sustainability standards are likely to be required, such as those required under the Renewable Energy Directive, to ensure genuine emissions reduction. We will address the role and design of sustainability standards in our bioenergy review to be published in 2011.

- **Sustainability and land availability.** There is uncertainty over whether there will be sufficient land available to grow biofuels feedstocks given increased demand for food from growing populations. In addition, there is the potential for adverse impacts on biodiversity as more land is brought into production.

(ii) Scenarios for biofuels penetration in the 2020s

Given these considerations, we base our scenarios for biofuels penetration in the 2020s on the Gallagher Review, and analysis by the IEA (Box 4.9):

- In the Low and Medium scenarios the level of UK biofuels suggested in the Gallagher Review for 2020 defines the amount of biofuels available in the 2020s (around 2.7 million tonnes of oil equivalent, or 31.2 TWh p.a.).

- The High scenario includes biofuels penetration according to the Gallagher Review in 2020s, rising above this in line with the IEA’s BLUE Map scenario through the 2020, such that there is a 95% increase in UK biofuel consumption between 2020 and 2030.

**Box 4.9: Biofuel assumptions in CCC scenarios**

Biofuels in our Low and Medium scenarios are consistent with the Gallagher Review, which recommended a range for use of sustainable biofuels in the UK of 5-10% of total fuel consumption (4-8% of total energy for road transport) in 2020. Reflecting this, the Extended Ambition scenario includes uptake of biofuels reaching a total of 10% by volume (8% by energy), equating to 2.7 mtoe (31.2 TWh) in 2020.

The Low and Medium scenarios are both based on the conservative assumption that uptake of biofuels is limited to the Extended Ambition level of 2.7 mtoe between 2020 and 2030. Abatement from biofuels is therefore fixed at around 8 MtCO₂.

Biofuels in our High scenario are consistent with the International Energy Agency’s BLUE Map scenario. Under this scenario,

- total global transport energy use increases from around 2150 mtoe in 2007 to 2760 mtoe in 2050, and
- total global biofuel consumption increases from 34 mtoe in 2007 to 745 mtoe in 2050.

Assuming a linear increase in both total transport energy use and biofuel consumption suggests

- total global transport energy use of around 2476 mtoe in 2030, and
- total global biofuel consumption of around 414 mtoe in 2030.

Our High scenario is based on the principle that the UK’s share of total global biofuel consumption should be equal to its share of total transport energy consumption. To establish the appropriate UK share of total transport energy consumption, we estimate UK energy consumption in 2030 if it were on a path consistent with the IEA BLUE Map scenario at 30.9 mtoe, or 1.2% of global transport fuel use.

This implies a share of biofuels for the UK of 1.2% of the global total of 414 mtoe in 2030, or 5.2 mtoe (60.8 TWh). We model linear take up from 2.7 mtoe in 2020 to 5.2 mtoe in 2030.
(iii) Possible roles for biofuels in road transport, emissions reduction and costs

Roles for biofuels

Whilst biofuels will not by any means provide the sole basis for transport decarbonisation in the 2020s, our scenarios suggest that they have a potentially important role in catering for market segments where there is limited scope for emissions cuts through electrification:

- **Conventional cars and vans**: In our Medium and High scenarios for penetration of electric vehicles (Section 3) and hydrogen vehicles (Section 5), the car fleet will still comprise 60-69% conventional vehicles and the van fleet 58-71% conventional vehicles in 2030.

- **Plug-in hybrid vehicles**: Our scenarios allow for the possibility that there may be significant uptake of plug-in hybrid rather than pure electric vehicles. Biofuels offer a good opportunity for cutting emissions from plug-in hybrids for those journeys beyond the electric range.

- **Buses and coaches**: In our Medium and High scenarios for penetration of hydrogen buses and coaches (Section 5), the combined bus and coach fleet will still comprise 94-96% conventional vehicles in 2030.

- **HGVs**: There is limited scope for use of battery electric technologies on HGVs given technical barriers. Therefore biofuels are a key option for decarbonising HGV emissions.

We estimate that total demand for conventional fuel in 2030 from these various segments could be up to 27 million tonnes of oil equivalent (315 TWh) in our Medium electric car and van scenarios, compared to available sustainable biofuels of up to 2.7 mtoe (31.2 TWh). Therefore sustainable biofuels make a significant contribution in our scenarios notwithstanding significant deployment of electric vehicles through the 2020s.

Emissions reduction from biofuels

Given scope for biofuels to complement rather than displace other abatement options, these will result in emissions savings:

- In the Low and Medium scenarios, biofuels do not deliver emissions savings beyond those achieved by the reference emissions projection.

- In the High scenario, emissions savings are around 7 MtCO₂ in 2030 greater than those achieved by the reference emissions projection.

Notwithstanding issues around lifecycle emissions, these savings assume that biofuels are zero carbon in line with the definition of the Net Carbon Account under the Climate Change Act. We will consider lifecycle emissions in more detail in our bioenergy review to be carried out in 2011.

Costs of biofuels

Biofuels abatement costs are a function of production costs and the relative cost of petrol and diesel, both of which are highly uncertain. IEA analysis aims to address this uncertainty and provides a range of cost estimates compared to the oil price:

- For an oil price of $60/bbl the IEA analysis suggests that there is a 39% cost penalty for biofuels.

- At $120/bbl the IEA estimates that biofuels are 16% cheaper than conventional fuels.

- DECC’s central projection is of an oil price around $90/bbl in 2030, in which case the cost of biofuels and conventional fuels is broadly similar.

Therefore our scenarios for biofuels penetration do not involve any cost under DECC’s central case price projection. Under a low oil price projection, costs in the Medium scenario would be around 0.02% of GDP in 2030, whereas under a high oil price projection there would be a saving of around 0.01% of GDP in 2030.

5. Opportunities for use of hydrogen in vehicles

Overview of hydrogen transport technologies

In contrast to biofuels, but similar to electricity, hydrogen is a carrier of energy rather than a source. It can be produced via electrolysis (using electricity to decompose water), gasification of biomass or coal and reforming of natural gas or biomethane. Each of these processes is potentially low-carbon (e.g. with electrolysis based on low-carbon power generation, and with carbon capture and storage for natural gas reforming or coal gasification).

Hydrogen can then be used in transport either in fuel cells (i.e. to generate electricity onboard the vehicle) or in internal combustion engines (ICEs) – use in fuel cells is expected to have a significant efficiency advantage, as they are electrochemical devices and therefore are not subject to the thermodynamic limits of ICEs. There are currently a number of projects demonstrating fuel cell technology for cars, vans, buses and motorbikes (Box 4.10).
### Box 4.10: Hydrogen fuel cell demonstration projects

**Buses:**
- The Clean Urban Transport for Europe (CUTE) project demonstrated three Daimler-Chrysler Citaro fuel cell buses for three years in each of nine European cities between 2003-2007. Associated projects demonstrated a further three buses each in Reykjavik and Perth, Australia.
- Following a three-year trial of three hydrogen-powered fuel cell buses as part of the CUTE project in 2004-2007, eight new hydrogen buses (both fuel cell and ICE hybrids) are due to commence service by the end of 2010, operating on the RV1 bus route in London.

**Cars:**
- The Honda FCX Clarity, which has a driving range of around 400 km, is being leased to members of the public in California, Japan and Europe.
- The Mercedes-Benz F-CELL hydrogen vehicle was used during the 2010 US Open tennis tournament, and represented a significant portion of the fleet used for player and VIP transportation.
- About 5,000 people have driven the fuel cell Chevrolet Equinox in short test drives, as part of Project Driveway, testing the vehicle in California, Berlin and Beijing.
- The world’s first fuel-cell driven street cleaning vehicle, Proton Motor Empa Bucher CityCat H2, has been in use in the city since 2009.
- Thirty of the RiverSimple two-seater cars will be demonstrated in Leicester from 2012. This vehicle has taken a radical approach to vehicle design, using lightweight materials to reduce fuel consumption, giving the vehicle an efficiency equivalent to around 300 miles per gallon.

**Taxis, utility vehicles and vans:**
- A fleet of Lotus Engineering Zero Emission Black Cabs should be operational for the London 2012 Olympics.
- West Midlands: Five fuel cell vehicles in routine utility applications such as postal deliveries on the University of Birmingham Campus were tested over a year.
- Basle, Switzerland: The world’s first fuel-cell driven street cleaning vehicle, Proton Motor Empa Bucher CityCat H2, has been in use in the city since 2009.
- The ITM Power Hydrogen on Site Trials Programme (HOST), starting in 2011, encompasses the operation and refuelling of two Revolve Technologies hydrogen Ford Transit vehicles. Participants include public sector organisations, logistics providers and utility companies.

**Further developments:**
- A memorandum of understanding has been signed in Germany between leading industrial companies and the Government, agreeing plans for a nationwide infrastructure of Hydrogen fuelling stations by the end of 2011. The H2 Mobility initiative anticipated several hundred thousand hydrogen fuel cell vehicles from 2015.

*Sources:* GAI, London Hydrogen Partnership, Mercedes-Benz, RiverSimple, ITM Power, Honda and DECC websites.

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The use of hydrogen in fuel cells generates electricity onboard the vehicle, rather than requiring electricity to be stored directly in a battery. This decoupling of energy storage (hydrogen) from electricity delivery (the fuel cell) enables hydrogen vehicles to have greater range than battery electric vehicles. The reason for this is that increasing the range is a matter of increasing the volume of hydrogen storage, rather than increasing the size of the fuel cell. It therefore seems possible that there is an important future role for hydrogen PHEVs (i.e. vehicles with a battery to cover shorter journeys and a fuel cell plus hydrogen storage to enable longer journeys).

### Challenges in producing low-carbon hydrogen at scale

In order for hydrogen fuel cell vehicles to deliver substantial emissions reduction, the hydrogen would need to be produced by low-carbon processes, which include:

- **Electrolysis using low-carbon electricity.** Although hydrogen production in this way is relatively inefficient thermodynamically, it has the advantage that the hydrogen could be generated when low-carbon generating capacity is underutilised (e.g. if a nuclear or CCS plant were generating electricity with a load factor of 50% or 60% rather than 90% – see Chapter 6 for discussion of this). This would imply a more distributed system of hydrogen production – with production taking place at or near hydrogen fuel stations – rather than the extensive use of pipelines or the energy-intensive hydrogen liquefaction process that would enable distribution by road.

- **Direct production from fossil fuels with ‘pre-combustion’ CCS.** Subject to the successful demonstration of pre-combustion CCS, hydrogen could be co-produced with electricity at large-scale directly from fossil fuels. The plant could produce electricity at peak times and hydrogen for transport off-peak (e.g. overnight). This method of hydrogen production is more thermodynamically efficient than electrolysis, but would result in hydrogen being produced at relatively large scale at power plant sites, and would therefore require considerable infrastructure (e.g. dedicated hydrogen pipelines) to transport it to areas of demand.

- **Production from bioenergy.** E.g. via gasification of biomass or reforming of biomethane. Using biomethane delivered via the gas grid would enable distributed production, avoiding the need for hydrogen distribution. However, there are many possible uses for bioenergy, so hydrogen would have to compete with other uses for this finite resource.
Challenges to deployment of hydrogen vehicles

Each of the processes above involves significant challenges (e.g. they would require power sector decarbonisation, or technology innovation, or abundance of sustainable bioenergy). In addition to these production challenges, other challenges relating to storage and distribution would make it easier for widespread deployment of this technology:

- There are challenges in hydrogen storage, particularly inside a vehicle. Compressed hydrogen is used for storage onboard most of the current hydrogen demonstration vehicles, which typically have a range of around 400 km (e.g. the Honda FCX Clarity). However, the weight and relatively low energy density of this solution mean that there is substantial scope for improvement. Liquid hydrogen has a greater energy density, but is very energy-intensive to produce. Research into alternatives with suitable characteristics for vehicular hydrogen storage is ongoing.

- Where hydrogen is produced at large scale away from areas of demand (e.g. with CCS), it will need to be transported. There are two main options for this, either using pipelines or liquefying the hydrogen and transporting it by road. Hydrogen pipelines are capital-intensive and expensive for long distances and/or small volumes. Laying of an extensive new hydrogen pipeline network may also face challenges relating to planning. For the liquid hydrogen option, the cost and energy consumption of the hydrogen liquefaction plant makes this expensive and energy-intensive.

Costs of hydrogen vehicles and fuel supply

From an economic perspective, use of hydrogen in vehicles is relatively expensive:

- Many ways of supplying hydrogen involve significant energy losses relative to generating electricity and using this via an electric car battery rather than a fuel cell (Box 4.11)

- The challenges in hydrogen storage and distribution have significant infrastructure cost implications, more so for centralised large-scale hydrogen production (e.g. from pre-combustion CCS).

- Hydrogen vehicle costs have so far not fallen to a point where they are competitive with conventional vehicles.

Estimates of hydrogen abatement costs are therefore relatively high compared to those for electric vehicles (e.g. around £220/tCO₂ for cars in 2030, (Box 4.12).
Feasible uses of hydrogen in transport

The principal advantage of hydrogen over electric vehicle batteries is for applications for which pure battery electric vehicles are unsuitable, e.g. vehicles requiring longer range. Therefore if challenges in hydrogen infrastructure development can be addressed, there may be a useful role in niche markets, with more widespread deployment if for some (unanticipated) reason battery electric vehicles do not fulfil current promise:

- Buses provide a good opportunity for hydrogen given depot fuelling.
- Hydrogen could be used in HGVs with depot fuelling and fuelling stations along motorways and main roads.
- High-mileage fleet vans could use hydrogen based on depot fuelling.
- Widespread uptake of hydrogen cars and vans would require major investment in a national network of hydrogen fuelling stations, at a scale close to that for petrol and diesel today, together with an accompanying infrastructure for hydrogen production and distribution.

Scenarios for hydrogen vehicle take up in the 2020s

We have developed three scenarios for deployment of hydrogen fuel cell vehicles in the 2020s reflecting different assumptions on the extent to which current barriers are addressed and uptake in niche markets versus more widespread deployment:

- Under our Low scenario take up of fuel cell vehicles is limited to a small number of demonstration projects and these vehicles do not achieve a significant market share for any mode. Emissions reduction from fuel cell vehicles is assumed to be negligible.

- Our Medium scenario models achievement of low-carbon hydrogen production and the availability of vehicles at reasonable cost such that fleets capable of depot-fuelling can deploy fuel cell vehicles, but without the development of a (partial or more extensive) national distribution network. In this scenario uptake is limited to buses, which come in around 2025 and account for a market share of 50% of new buses in 2030.

- Our High scenario models a world where challenges in production, storage and distribution are addressed, such that there is a national fuelling network in place supporting uptake in cars, vans, HGVs and buses:
  - Take up in cars and vans begins in 2025, with market share rising to 10% in 2030.
  - Take up in HGVs and coaches begins in 2025, with market share rising to 20% in 2030.
  - Take up in buses begins in 2021, with market share rising to 50% in 2030.
Hydrogen supply in the Low and Medium scenarios is assumed to be from off-peak decentralised electrolysis. In the High scenario, a combination of off-peak distributed electrolysis and large-scale production from fossil fuels with CCS is assumed, with distribution where necessary via dedicated hydrogen pipelines.

6. Ongoing role for demand-side emissions reduction

We assume in this chapter that the demand-side emissions reduction achieved in the period to 2020 (4.9 MtCO\textsubscript{2} in 2020) persists through the 2020s. Policy levers are likely to be required to lock in this emissions reduction, given evidence that consumers may revert to previous behaviours beyond an initial period (e.g. network measures and ongoing implementation would help to reinforce initial impacts of Smarter Choices programmes, etc.).

In addition to locking in pre-2020 emissions reduction, there are also opportunities for further emissions cuts in the 2020s through encouraging behaviour change and other demand-side measures:

- Given that there could still be up to 69% conventional cars in the car fleet in 2030, there is scope for further emissions cuts through demand-side measures. For example:
  - The effects of Smarter Choices measures on travel choices could be increased with greater investment in public transport infrastructure (e.g. light railway systems).
  - Adoption of eco-driving by the 80% of drivers remaining untrained by 2030 in our reference emissions projection.
  - The introduction of road pricing, which would also be consistent with the Government’s objective to increase the proportion of tax revenue accounted from environmental taxes.

- CLG forecast that the number of households will increase by around 6.3 million in England by 2030. This will translate to increased demand for housing and building of new houses. Although in themselves new houses will be zero-carbon (see Chapter 5), there is a risk that these will be located far from places of work, and therefore that transport emissions will increase. This underscores the importance of developing an integrated land-use and transport planning strategy to ensure that decisions on new residential and commercial developments fully account for transport emissions.

7. The role for decarbonised rail

Direct rail emissions were 2.2 MtCO\textsubscript{2} in 2008, and indirect (i.e. electricity related for that part of the network which is electrified) 1.8 MtCO\textsubscript{2}; in total, the share of rail emissions in total surface transport emissions was around 3%.

In the period to 2020 demand for rail travel is expected to increase by around 35%, with emissions from diesel trains decreasing by around 12%, with the emissions impact for electric trains uncertain given scope for significant reduction in the carbon intensity of power generation over the next decade (see Chapter 6).

Our Extended Ambition scenario to 2020 includes a small emissions reduction (around 0.6 MtCO\textsubscript{2} in 2020) to reflect scope for efficiency improvement both due to the introduction of new trains and through initiatives by passenger and freight operating companies to save energy.

Electrification of rail

In the medium term, there is scope for emissions reduction through increased electrification. Electric rail is much more carbon efficient than diesel rail even based on current grid carbon intensity, with emissions of around 50 gCO\textsubscript{2} per passenger-km compared to 75 gCO\textsubscript{2} per passenger-km for diesel, and scope for deep emissions cuts with an increasing proportion of low-carbon generation.

Electrification of the entire rail network combined with zero-carbon electricity generation would reduce emissions from rail to zero. The scope to achieve 100% electrification would be limited by:

- The cost of electrifying the track, which varies depending on the specific features of each section of track, e.g. elevation, cutting, tunnels etc.
- The cost of alternatives to electrifying the track (e.g. discontinuous electrification, where a train has batteries which charge on the electrified portion of a track to supply electricity to an electric motor that can power the train on sections of track that are too costly to electrify) or the use of other energy sources e.g. bio diesel.
- The cost savings realised from electrification of the railway lines resulting from the lower operating costs of electric trains; the cost savings will be greater on lines with high passenger demand (and therefore energy consumption), and lower on lines with low passenger demand.
- The feasibility of investment in sufficient additional low-carbon generation capacity to accommodate the increase in electricity demand from electrification of the rail network given the very challenging investment schedule required to meet demand from electric vehicles and heat pumps (see Chapter 6).
High-speed rail

There is also the possibility of high-speed rail, for example, the proposed High Speed 2 linking London to Birmingham, and beyond to the North of England and Scotland (Box 4.14). The main means for this to reduce emissions is through switching from domestic and short-haul aviation. In our review of UK aviation emissions, we assessed a maximum potential emissions reduction of 2 MtCO₂ annually through switching from aviation to high-speed rail, with two caveats that this would require a low-carbon electricity system, and would also need complementary levers such as withholding any slots released at capacity constrained airports.

Box 4.14: High Speed 2

The previous Government’s proposals for high-speed rail are set out in ‘High Speed Rail for Britain’. It stated that High Speed 2 would transform the long-distance rail market, reducing capacity constraints of the West Coast Main line, lowering journey times, as well as providing opportunities for regeneration and development. The report states an inconclusive impact on total transport (surface transport and aviation) emissions, ranging from a reduction of 25 MtCO₂ to an increase of 27 MtCO₂ over a 60 year period.

First stage proposals suggest building a track capable of speeds up to 400 kph, between London Euston and Birmingham, to be later extended through a 335 mile high speed rail network in a Y-Shape to cities further north, including Liverpool, Manchester, Leeds and potentially Edinburgh and Glasgow.

The coalition manifesto supports proposals for a high-speed rail network as part of their measures for creating a new low-carbon economy, but also accepts, given financial constraints, that this would have to been done in phases. In the 2010 Spending Review the Government confirmed that it will bring forward legislation during this Parliament that would allow the project to proceed.

Source: High Speed Rail for Britain (March 2010)

We estimate that the effects of the high-speed rail proposals on surface transport emissions (i.e. the combined effect of the increase in emissions from electricity generation and any reduction in car emissions through modal shift) would be negligible.
8. The role of freight operations and logistics

Trends and projections at the UK level

Freight comprises around 24% of surface transport sector and 5% of total UK CO2 emissions. Road travel dominates freight movements, carrying two-thirds of goods moved – a large share compared to other EU countries.

CO2 emissions of HGVs – which account for the largest share of road freight movements – have been broadly stable at around 24 MtCO2 since 1990:

- This has happened against a background of increasing amounts of freight tonnes lifted by all modes (around 4% greater in 2008 compared to 1990) and a 20% increase in road tonne-km travelled.

- Despite increased journey lengths since 1990, average HGV payloads have increased and there has been a reduction in the amount of empty running. Consequently, HGV vehicle-km travelled has increased at a slower rate (15%) than the amount of tonne-kms travelled.

- HGV carbon intensities have also fallen since 1990, by around 14%, which when combined with the other trends means that total emissions have remained broadly flat.

However van emissions have been rising over the same period (the reason for this increase is not known but the Commission for Integrated Transport argue that it is largely due to an increase in home deliveries associated with online shopping). Thus since 2000 the trend in total van and HGV emissions has been upwards.

Abatement opportunities

Abatement in freight can be achieved through reducing either distances travelled (measured in vehicle-km) or carbon intensity of travel (measured in gCO2/km). Evidence suggests that there are particular opportunities for abatement from modal shift, supply chain rationalisation and better vehicle utilisation (Box 4.15):

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<td>• Supply Chain rationalisation – optimising distribution centre locations, sourcing produce locally and greater use of consolidation centres.</td>
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Various scenarios for freight emissions suggest scope for significant reduction (Box 4.16). However, these scenarios are highly uncertain, and further evidence is required on:

- The long-term potential for transfer of freight from road to rail and water transport and cost-effectiveness of further network/infrastructure investment.

- Availability of backhauls and load sharing opportunities which could be taken up by hauliers in the 2020s.

- Abatement potential from changes in business practice such as just in time delivery, vendor managed inventories and supply chain event management.

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Box 4.16: Freight scenarios

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<th>Scenario</th>
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<tr>
<td>1</td>
<td>Total HGV distance reduces from 29 billion vehicle-km in 2007 to 35 billion in 2030 and 41 billion in 2050</td>
</tr>
<tr>
<td>2 ('current policy direction')</td>
<td>Total distance reduces to 33 billion vehicle-km in 2030 (a 7% reduction over business as usual) and 35 billion in 2050 (a 14% reduction). This scenario is consistent with our reference emissions projection.</td>
</tr>
<tr>
<td>3</td>
<td>Total distance decreases to 28 billion vehicle-km in 2030 (a 19% reduction over business as usual) and 26 billion in 2050 (a 36% reduction)</td>
</tr>
<tr>
<td>4</td>
<td>Total distance decreases to 27 billion vehicle-km in 2030 (a 23% reduction over business as usual) and 22 billion in 2050 (a 47% reduction)</td>
</tr>
</tbody>
</table>

We model two scenarios for reduction in HGV vehicle-km:

- HGV vehicle-km in our Medium Abatement scenario are 6.5% lower than the reference
- HGV vehicle-km in our High Abatement scenario are 13% lower than the reference. This is consistent with the reduction delivered by DECC’s Scenario 3 over Scenario 2 (current policy direction).

9. Surface transport emissions scenarios for the 2020s

The path to 2030

Our surface transport abatement scenarios are built up from the scenarios for more efficient conventional vehicles, electric vehicles, biofuels and hydrogen vehicles (see Figures 4.13-15):

- The Low Abatement scenario (i.e. the combination of Low scenarios for individual measures) results in surface transport emissions of 72 MtCO₂ in 2030, compared to emissions in the reference emissions projection of 79 MtCO₂ (i.e. a 8% reduction):
- Emissions in the Medium Abatement scenario are 67 MtCO₂ in 2030 (i.e. 15% lower than in the reference emissions projection).

- Emissions in the High Abatement scenario are 50 MtCO₂ in 2030 (i.e. 36% lower than in the reference emissions projection).

In our Medium Abatement scenario

- Average emissions intensity of cars falls by 39% from 132 gCO₂/km to 81 gCO₂/km, whilst distance travelled increases by 9% from 446 billion km to 485 billion km 2020-2030
- Average emissions intensity of vans falls by 33% from 175 gCO₂/km to 118 gCO₂/km, whilst distance travelled increases by 24% from 92 billion km to 114 billion km 2020-2030 (Figure 4.16).

The cost in the Medium Abatement scenario is in the range -0.1 to 0.2% of GDP in 2030 depending on assumptions about technology costs and fossil fuel prices (Table 4.1).

We incorporate these scenarios and cost estimates into our economy-wide analysis of options for meeting the fourth carbon budget in Chapter 3.

Table 4.1: Cost sensitivity

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost (£m)</th>
<th>% GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central costs:</td>
<td>£1,890</td>
<td>0.08%</td>
</tr>
<tr>
<td>High capital costs:</td>
<td>£3,773</td>
<td>0.17%</td>
</tr>
<tr>
<td>Low capital costs:</td>
<td>£7</td>
<td>0.00%</td>
</tr>
<tr>
<td>High fossil fuel prices:</td>
<td>-£2,595</td>
<td>-0.11%</td>
</tr>
<tr>
<td>Low fossil fuel prices:</td>
<td>£4,133</td>
<td>0.18%</td>
</tr>
</tbody>
</table>

Figure 4.14: Medium Abatement scenario surface transport abatement and emissions (2020-2030)

- Conventional vehicle efficiency
- Electric vehicles
- Plug-in hybrid vehicles
- Residual emissions

Source: CCC analysis.

Note(s): Emissions reductions are calculated against reference emissions projection, which already includes some abatement from electric vehicles and other technologies. The low reductions from conventional vehicles reflect the reduced stock of these vehicles due to greater take-up of these vehicles. Abatement includes 0.2Mt of abatement from hydrogen buses which is not visible due to scale.

Figure 4.15: High Abatement scenario surface transport abatement and emissions (2020-2030)

- Conventional vehicle efficiency
- Electric vehicles
- Plug-in hybrid vehicles
- Hydrogen vehicles
- Biofuels
- Residual emissions

Source: CCC analysis.

Note(s): Emissions reductions are calculated against reference emissions projection, which already includes some abatement from electric vehicles and other technologies. The low reductions from conventional vehicles reflect the reduced stock of these vehicles due to greater take-up of electric, plug-in hybrid and hydrogen vehicles.

Figure 4.16: Historical trends and Medium Abatement scenario projections of vehicle-km, MtCO₂ and gCO₂/km for cars (1990-2030)


Note(s): Indirect emissions from electric vehicles are minimal under our Medium Abatement scenario the CO₂ intensity of the grid is around 12g/KWh and indirect emissions for an electric car account for 2.4gCO₂/km.

Figure 4.17: Surface transport emissions in the context of UK greenhouse gas emissions (1990-2030, 2050)

- Indicative 2050 International aviation & shipping
- Indicative 2050 Non-CO₂
- Indicative 2050 CO₂
- Other GFG
- Surface transport

Source: NAEI 2010, CCC analysis.
The path from 2030 to 2050

Emissions in 2030 are 67 MtCO₂ in our Medium Abatement scenario, with further reduction required to 2050 including (Figure 4.17):

- A low or zero-carbon car and van fleet, comprising electric and plug-in hybrid vehicles, with the possibility of hydrogen vehicles.
- The possibility of hydrogen HGVs.
- Biofuels meeting demand for residual liquid fuels (e.g. from plug-in hybrid vehicles, HGVs).
- Rail electrification

Given our assessment of what is possible in other sectors, it is likely that an emissions reduction of 90% or more will be required in surface transport to meet the economy-wide 80% target. The implication of this is that conventional cars and vans should be fully phased out by the mid-2030s, in order that the car and van fleet is zero- or low-carbon by 2050.

10. Implications for first three budget periods

The main implications for the first three budget periods relate to electric vehicles, biofuels and hydrogen:

- **Electric vehicles.** It is unlikely that there could be very significant roll-out of electric cars and vans in the 2020s from a standing start in 2020. Therefore in order to support required decarbonisation in the 2020s, it will be important to make progress on electric vehicle deployment in the first three budget periods. This reinforces the need for transitional Government support to cover the cost of electric car batteries, together with investment in a battery recharging network. In addition, the economics of electric vans should be assessed in more detail and transitional support arrangements introduced as appropriate. Assessment of network implications from significantly increased penetration of electric cars should be undertaken and used to inform design of investment programmes.

- **Second generation biofuels.** Research, development and demonstration of second generation biofuels is required if these are to play an important role in the 2020s. Consideration should be given to options for supporting R&D and pulling through second generation biofuels (e.g. through a requirement to meet EU biofuels targets with a greater proportion of second generation biofuels).

- **Hydrogen.** There should be continued support for hydrogen technologies as part of a wider technology strategy in order to support deployment in the 2020s in markets where vehicle range is of particular importance.

The Committee will continue to monitor progress developing a framework for and rolling out electric cars in the period to 2020, and will explore scope for adding indicators relating to progress in electric vans, second generation biofuels, and hydrogen.

11. Key findings

44% emissions reduction in surface transport can be achieved by 2030.

60% of new cars and vans in 2030 could be electric.

Potential volume of biofuels consumed each year during 2020s.

Potential carbon efficiency of new conventional cars in 2030.

50% of new buses in 2030 could be powered by hydrogen.

Potential reduction in car trips from smarter travel choices.

Potential cost of reducing surface transport emissions by 44%.