Market Delivery of Ultra-Low Carbon Vehicles in the UK

An evidence review

Ben Lane

January 2011

RAC Foundation

Ecolane
Transport Consultancy

The Royal Automobile Club Foundation for Motoring Ltd is a charity which explores the economic, mobility, safety and environmental issues relating to roads and responsible road users. Independent and authoritative research, carried out for the public benefit, is central to the Foundation's activities.

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About the author

Ecolane's director Dr Ben Lane has over a decade of experience within academic research and independent consultancy. His work has included a wide range of transport related environmental fields including cleaner vehicle technologies and non-car travel modes. Advising government, local authorities and businesses on how to reduce transport emissions, he has build up a strong reputation for in-depth analysis with a particular focus in the following key areas: life cycle analyses of cleaner vehicle technologies, vehicle environmental ratings, and car buyer attitudinal research. He is also co-founder of the consumer green car website www.nextgreencar.com.

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Foreword

The clock is ticking. The provisions of the Climate Change Act mean the UK must cut its greenhouse gas emissions by 80% by 2050 relative to 1990 levels.

As one of the biggest emitters of carbon dioxide, the transport sector - particularly the personal car market – has its work cut out to help meet this target.

The good news is that car manufacturers are responding to the challenge and we are approaching a point where there will, indeed must, be a fundamental shift away from vehicles powered by fossil fuels.

The bad news is that there is no unanimity on how close we are to that tipping point. Some believe it to be round the next corner, others say it is still out of sight over the horizon.

The uncertainty is caused less by the technological aspects of the problem – we are already seeing a wide range of low carbon vehicles either on the market or about to be brought to it – than consumer behaviour.

Put another way, the supply side of the low carbon vehicle market is coming under control, but how we create meaningful demand for the products is not.

As this report highlights, there is a list as long as your arm of reasons why people might not be rushing out to buy green. Those reasons include concerns about: price, reliability, resale value, range and practicality, desirability, fuel efficiency.

But more fundamentally there is still a big hole in consumers' knowledge of what low and ultra-low carbon cars actually are. The buying public are not helped by confusion and disagreement amongst manufacturers and policy makers.

In this review, "an ultra-low carbon vehicle (ULCV) is defined as one which conforms with European 'M1'-type approval standards, and has the potential to operate with 'well-to-wheel' CO2 emissions of less than 75 gCO2/km, as measured on the New European Drive Cycle (or similar) (DfT, 2009a)."

I'd like to hear the car salesman explain that to a customer being harassed by his or her children on a wet Saturday afternoon in the showroom.

But explain it they must if we have any hope of seeing the 1.7 million plug-in electric vehicles on the roads by 2020 as encouraged by the Committee on Climate Change.

The Government's recently launched scheme offering grants of up to £5,000 to purchasers of the greenest cars is to be welcomed, but it must be the start of the incentive process, not the end, because with 28 million cars on the UK's roads we clearly have a long way to travel.

With time so pressing it is also critical policymakers travel down the right road and not up too many cul-de-sacs. This report should help them map out that route.

Dr Stephen Hammerton
Trustee, RAC Foundation

Executive Summary

The evidence reviewed suggests that the emerging ultra-low carbon vehicle (ULCV) market is at a critical phase. New vehicle technologies have received significant global interest and investment for several decades, but only now has the technology evolved to a stage where the mass commercialisation of ULCVs can be realistically contemplated. With several high-quality models being prepared for launch, 2011 and 2012 are likely to be crucial years, marking the start of a mass market, particularly for electric vehicles.

However, no matter how ready the technology, consumer willingness to adopt ULCVs will be central to initiating the market shift away from conventional vehicles. Although consumers are engaged with climate change, the evidence shows that this concern will not be sufficient on its own to stimulate demand. To reach the mass market, the average car buyer will also need to be convinced that ULCV models on offer are affordable, reliable and – most importantly – desirable.

The review provides clear evidence that the current level of public awareness and knowledge of ULCVs is relatively low, particularly when it comes to plug-in hybrids and fuel cell vehicles. Even regarding battery electric vehicles, the most commonly known type of ULCV, the average consumer has little detailed knowledge about their operation, driving experience or potential benefits.

While the review provides evidence that information alone is not sufficient to markedly influence consumer behaviour, it also makes it clear that providing information is necessary as part of a wider promotion strategy. More importantly, the evidence demonstrates that providing opportunities for consumers to get ‘hands-on’ experience of ULCVs is very effective in raising expectations and increasing consumer acceptance.

In addition to noting the industry’s need to improve the measurement of environmental impact of new vehicle types, the review reports that a growing minority of consumers are interested in life cycle information (including ‘well-to-tank’ fuel-related emissions, vehicle production and recycling). Research is therefore required to assess the most effective and understandable metrics with which to convey the life cycle impacts of new technologies such as plug-in electric vehicles.

The literature also highlights an important aspect of car ownership – the symbolism attributed to particular makes, models and vehicle types. Through ownership, car buyers communicate to others who they are: their interests, beliefs, values, and social status. Any car can have symbolic value, but the evidence suggests that symbolism is particularly strong for vehicles that use new types of technology. Understanding how ULCVs are valued by consumers will, therefore, provide unique insights into the most effective promotional and marketing strategies.

Regarding costs of ownership, the review notes that the purchase price for most types of ULCV remains a key barrier to their adoption by the mass market. Given that the willingness-to-pay for new vehicle technologies tends, for early adopters, to be limited to a premium of around 15% on the price, and is less for later-adopting market segments, financial incentives are likely to be needed in order to stimulate mass consumer demand.

The review observes that the incentives offered through circulation taxes (taxes, such as the Vehicle Excise Duty in the UK, that are charged on a periodic basis, confer the right to use the public road network, and are imposed independently of the mileage driven) are not sufficient in themselves to promote a significant switch to new vehicle technologies. Instead, the review provides compelling evidence in support of incentives applied at the point of purchase – the rationale being that purchase price is one of the most important factors influencing vehicle choice. In particular, the review highlights the success of ‘feebates’, which combine an integrated system of registration fees for the most polluting vehicles with rebates for cars with the lowest emissions.

While the government’s new Plug-in Car Grant – available from January 2011 – will go some way towards incentivising sales of quality ULCVs in the short term, capital incentives are likely to be needed over the longer term to sustain consumer demand. The review concludes, therefore, that a self-financing system – such as a ‘feebate’ scheme – will be required, and notes that, to date, few in-depth studies have designed such a scheme for the UK, or assessed its likely effectiveness.

Regarding the provision of a recharging infrastructure for electric vehicles, the review notes that around 80% of UK car-owning households already have access to a garage or other off-street parking facility, and finds that the existing electricity supply accessed through standard home-based (13A) sockets will be sufficient to support a significant switch to electric vehicles.

However, it also notes that there is little or no home-charging support for consumers contemplating owning an electric vehicle. Considering the significant investment currently being made to expand the public-access recharging network, this implies that ULCV adoption could be more effectively promoted by supporting consumers wanting to recharge at home.

The review highlights the benefits of supporting home recharging, at the same time acknowledging that on-street charging infrastructure may be necessary from an attitudinal perspective to encourage ULCV adoption. The central questions here are: on what scale are public access recharging locations really required (in terms of their level of utilisation), and to what extent should resources be focused on supplying them in sufficient numbers to provide psychological reassurance?

Regarding consumer-focused policies intended to support the use of ULCVs, one issue arising during the review is the need to further harmonise local and regional measures – there is at least some anecdotal evidence of the confusion caused, for example, by the different extent and level of parking and charging incentives used by different London boroughs to promote the use of electric vehicles.

Regarding a specific policy, the review highlights the King Review's recommendation that the 'New European Drive Cycle', which generates the official CO_2 emissions and 'combined' fuel economy data for all cars sold in the EU, should be reviewed as regards its ability to reflect actual environmental impact of existing and future vehicle types. This issue is particularly pertinent for ULCVs, as the refuelling cycles have yet to be standardised – and also relates to the need to provide concise and easy-to-understand life cycle information to consumers.

Drawing on the positive outcomes of the real-world trials, this review highlights the benefits of involving potential ULCV users in the innovation process in order to promote organisational learning – as adopted by innovation strategies such as Strategic Niche Management, which endeavours to support new innovations through 'smart' experimentation. To achieve a more inclusive innovation strategy, the review therefore recommends that there be a greater 'consumer voice' within the innovation networks already established, and proposes the establishing of a new organisation or forum to represent the emerging ULCV consumer.

With the consumer foremost in mind, and based on the evidence presented, this review concludes by making ten recommendations to the RAC Foundation regarding possible issues that merit further exploration – issues which could form the focus for future Foundation-funded research.

The ten research recommendations pertaining to issues for further exploration are as follows.

- Assess the future requirements for UK consumer-focused information regarding ULCVs, with particular focus on web-based sources.
- Assess the feasibility of providing consumers with the opportunity to test-drive ULCVs, either using existing networks or through a national network of test-drive centres.

- Assess the most effective methods of conveying life cycle information to UK consumers, particularly to take into account the life cycle implications of ULCVs.
- Understand the extent and importance of symbolism attributed to ULCVs in the UK.
- Design and assess the likely effectiveness of a technology-neutral UK purchase ‘feebate’ scheme for ULCVs.
- Explore low-cost methods of supporting UK consumers who want to charge ULCVs at home.
- Assess what scale of UK public access recharging locations is required for adoption of electric vehicles, and to what extent resources should be provided if their primary purpose is to provide psychological reassurance to the consumer.
- Compare local and regional UK policies supporting ULCVs, with a view to assessing the potential for further integration and standardisation across the UK.
- Assess the suitability of the current ‘New European Drive Cycle’ (the current industry-standard test cycle used for calculating fuel consumption figures) for reflecting the full emissions impact of existing low carbon and future ultra-low carbon vehicles.
- Consider the establishing of a new organisation or forum dedicated to understanding and representing (potential) owners of ULCVs.

1. Introduction

In this review, an ultra-low carbon vehicle (ULCV) is defined as one which conforms with European 'M1'-type approval standards, and has the *potential* to operate with 'well-to-wheel' CO_2 emissions of less than 75 gCO_2/km, as measured on the New European Drive Cycle (or similar) (DfT, 2009a).

Even though there is already a considerable amount of public and private sector activity that aims to further develop greener vehicle technologies,[1] the RAC Foundation believes the mass-market adoption of ULCVs will be influenced by both demand- and supply-side factors which include:

- vehicle attributes – driving range, maintainability, reliability, safety, comfort, driveability, image and style, and market perceptions;
- consumer attitudes – towards new fuels and technologies, towards environmental issues, and as expressed in their responses to tax signals, purchase incentives, and access charges;
- financial factors – purchase price, operating and maintenance costs, taxation policy as it affects purchase price, annual taxation, fuel or other energy tax, and road user charges;

1 A summary of current government policies and the challenges faced is set out in Lytton (2010).

- fuel infrastructure – the cost and implementation of energy supply and distribution systems (especially where they require substantial infrastructure investment);
- government regulation – at the local, regional, national and EU levels (e.g. CO_2 legislation for passenger cars in the EU); and
- manufacturing capacity – model availability, challenges set by new technologies (e.g. electric vehicles), and responses to government supply-side incentives.

Despite the importance of these issues and their influence on the market adoption of ULCVs, the Foundation is concerned that the demand-side factors may be under-investigated – that is to say that strategic issues are not being looked at sufficiently from the point of view of the vehicle purchaser and user.

Therefore, to help ensure the successful delivery of ULCVs, the benefits of which will be felt by road users and society as a whole, the RAC Foundation is funding a research programme to:

> study, and promote debate about, the technical, economic, social, policy and practical issues which will affect the potential for and reality of mass-market adoption of ultra-low carbon vehicle technologies – with particular emphasis on demand-side issues.

As an initial phase of this research, in June 2010, the Foundation commissioned Ecolane Transport Consultancy to undertake an evidence review to assess the existing level of knowledge regarding the market adoption of ULCVs, with a particular focus on demand-side issues including consumer attitudes to green vehicle technologies, receptivity to fiscal incentives, and the effectiveness of policies designed to stimulate the ULCV market.

Based on the outputs of the evidence review (which are detailed in this report), the Foundation intends to develop a discussion paper, and provide opinion on the focus and approach of future research regarding the UK market adoption of ULCVs. Guided by the findings of this report, and following consultation with relevant stakeholders, the Foundation intends to commission an original research project in 2011.

1.1 Review methodology

As the subject matter of this review is one of the key areas of the company's expertise, Ecolane has access to a large database of research papers and reports that focus on consumer attitudes to the environment, personal mobility, car purchasing and low/ultra-low emission vehicles. The database, which is continually reviewed and updated, includes papers from academic and discipline-specific sources, published journals and reports, and information accessed using Internet search engines.

Ecolane also has extensive contact with other experts in the transport and environment sector, which ensures that the consultancy is kept up to date on developments in the field, including unpublished research reports and papers.

Although emissions are not determined solely by the vehicle technology employed, the review focuses on the power-trains used by the majority of close-to-market ULCVs, which include:[2],[3]

- battery electric vehicles (BEVs), commonly referred to simply as 'electric vehicles';
- plug-in hybrid electric vehicles (PHEVs); and
- fuel cell vehicles (FCVs).

Using a publication list based on the Ecolane dataset, an initial list of 125 relevant publications was compiled with strong preference given to studies that:

- focused on EU and UK consumer adoption of, and/or market aspects of, ULCVs;
- were based on data collected and analysed since 2000, with preference given to more recent publications;

employed high-quality quantitative methods and/or qualitative methodologies that extended beyond stated preference; data collected from real-world trials was also strongly favoured.

2 Note that biofuels are not considered by the review, as the technological and consumer attitudinal factors influencing market development are very different from those that affect plug-in electric and hydrogen-fuelled vehicles. While some of the factors are transferable to 'flex-fuel' vehicles, which use bioethanol, there is relatively little current potential for the commercialisation of this technology in the UK.
3 While not fully explored in this review, it should be noted that a continuum of emission reduction technologies are being brought to market, many of which blur the simple distinctions as defined here. For example, while 'regenerative braking' was first successfully commercialised in hybrid vehicles, such systems are now beginning to be used to improve the fuel economy of conventional drive-trains.

Although ‘conventional’ hybrid electric vehicles (HEVs), such as the Toyota Prius, are not included in the definition of a ULCV, given the role of hybridisation as a first-step in the electrification of vehicle power-trains, the review includes useful lessons regarding the market adoption of hybrids where these are relevant and transferable to the emerging ULCV market.

Relevant findings from the US and Canada are also included in the review where the adoption issues concerned are either transferable to a UK context, or are missing from the European literature.

Of the initial list of 125 reports, research papers and presentations, some were discarded as part of the review process for reasons of scope, relevance or methodology. On completion of the review, at least 67 publications were used to contribute to this report – these are cited in the following pages.

2. The Promise of Ultra-Low Carbon Vehicles

'[The] almost complete decarbonisation of road transport is a possibility…' *(HM Treasury, 2007)*

While it is beyond the scope of this review to provide a complete overview of the benefits offered by ULCVs and the challenges posed by them, this section highlights the key environmental and economic issues, and provides some context regarding market potential in the UK.[4]

One point to note at the outset is that global ULCV market development is currently at a critical phase, one which could mark the start of a mass market for electric vehicles. BEVs have been trialled for several decades in the UK and elsewhere (Lane, 1998), but it is only recently that vehicle performance, production costs, government policy and consumer attitudes have each evolved to a stage where the commercialisation of ULCVs can be contemplated. Furthermore, the latest BEVs coming to market are characterised by their high quality, are 'M1'-category cars,[5] and are original equipment manufacturer (OEM) models rather than after-market conversions.

To illustrate the market-readiness of ULCVs, Figures 1 to 4 provide details of selected BEV and PHEV models which are being launched in 2011 and 2012 in the UK and US markets.

4 A comprehensive overview of low and ultra-low carbon fuels and vehicle technologies is provided by the King Review (HM Treasury, 2007; 2008).
5 As opposed to quadricycles, which are mass and power limited and are subject to different legislation.

These include the Mitsubishi i-MiEV, Nissan LEAF, Toyota Plug-in Prius, and Vauxhall Ampera, to name just a few of the models ready for market. Although still at the development stage, two important hydrogen fuel cell vehicles are detailed in Figures 5 and 6: the Mercedes Benz B-Class F-Cell, and the Honda FCX Clarity.

Optimism aside, one issue of particular pertinence to this review is that, while manufacturers, policymakers and industry analysts are broadly in agreement that the potential commercialisation of ULCVs is now possible, it is as yet unclear whether consumers will accept the technologies on offer. Indeed, as will be discussed in this review, there is much evidence to suggest that the factors thought most relevant by the automotive industry are different to those focused on by potential users.

2.1 Environmental benefits

While the key benefit of ULCVs is the reduction of life cycle greenhouse gases, quantifying the extent of potential emission reductions is far from straightforward due the range of assumptions made when comparing ULCVs with conventional vehicles. That said, the King Review estimates that, if the power sector can be decarbonised and expanded to meet the growing demand for road transport, a 90% reduction in vehicle emissions (per mile) is technically achievable by 2050.

In the short term, most vehicles will rely on the existing energy network including (in the case of BEVs and PHEVs) the national grid. In a comprehensive report conducted for the Committee on Climate Change,Element Energy estimates the life cycle (or 'well-to-wheel') carbon emissions for a 2009 BEV using the average UK mix electricity at 100 gCO_2/km (Slater et al., 2009).[6] The report notes that this estimate is comparable with the most fuel-efficient petrol and diesel cars currently available, and is significantly less than average new car tailpipe emissions of 165 gCO_2/km (2007).

6 Slater et al. (2009) base their calculations on an electric vehicle with energy use of 0.20 kWh/km, a charger efficiency of 85%, and a current grid carbon intensity of 0.50 $kgCO_2$/kWh (similar to the value of 0.55 $kgCO_2$/kWh quoted in Lytton, 2010).

Figures 1–2: Examples of ULCVs considered in this report

Mitsubishi i-MiEV BEV

Based on the Mitsubishi 'i' launched in 2007, the i-MiEV (Mitsubishi innovative Electric Vehicle) is an OEM electric version now available in the UK. The i-MiEV has been proving its reliability and usefulness on the UK's roads since 2007, and has been involved in official government end-user trials (the CABLED trial) since mid-December 2009; the i-MiEV can now be ordered in the UK for a January 2011 delivery. Mitsubishi have priced the i-MiEV at £23,990 (taking into account the £5,000 Plug-in Car Grant).

Vehicle Segment: City Car	**Electric Range:** 80 miles	**Battery Type:** Lithium-ion
Fuel Economy: 12.4 kWh/100km	**Top Speed:** 81 mph	**Battery Capacity:** 16 kWh

Nissan LEAF BEV

The LEAF is Nissan's first mass-produced electric vehicle. Unlike most other electric cars, the LEAF has been designed from scratch as an EV. The LEAF can already be ordered in the UK for March 2011 delivery, and from 2013, the UK's Sunderland plant will manufacture 50,000 units per year and battery packs for the European market. The LEAF is priced at £23,350 (taking into account the £5,000 Plug-in Car Grant).

Vehicle Segment: Small Family	**Electric Range:** 100 miles	**Battery Type:** Lithium-ion
Fuel Economy: 15 kWh/100km	**Top Speed:** 90 mph	**Battery Capacity:** 24 kWh

Source: Descriptions and data supplied by Next Green Car (www.nextgreencar.com)

Figures 3–4: Examples of ULCVs considered in this report

Toyota Prius PHEV

Toyota announced the introduction of the Prius Plug-in Hybrid in July 2007, a plug-in version of their latest third-generation Prius Hybrid. According to Toyota's Executive Vice President, if the current vehicles leased to public organisations, police and businesses perform well, at least 50,000 Plug-in Priuses are expected to be sold a year globally, beginning in 2012.

Vehicle Segment: Large Family	**Electric Range:** 12.5 miles	**Battery Type:** Lithium-ion
Fuel Economy (blended): 2.3 litres/100km	**Top Speed:** 112 mph	**Battery Capacity:** 5.2 kWh

Vauxhall Ampera E-REV

Following the trialling of several prototypes in 2010, the Ampera is expected to go on sale in 2012. The Ampera, which is an 'extended-range electric vehicle', uses one of the largest batteries of any plug-in hybrid in conjunction with a 1.4L petrol engine acting as a generator. While Vauxhall estimate the initial production levels to be around 10,000 per year, the purchase price has yet to be confirmed.

Vehicle Segment: City Car	**Electric Range:** 80 miles	**Battery Type:** Lithium-ion
Fuel Economy: 12.4 kWh/100km	**Top Speed:** 81 mph	**Battery Capacity:** 16 kWh

Source: Descriptions and data supplied by Next Green Car (www.nextgreencar.com)

Figures 5–6: Examples of ULCVs considered in this report

Mercedes Benz F-Cell

The Mercedes-Benz B-Class F-Cell fuel cell vehicle has a performance similar to that of a 2.0 litre petrol car, and uses compressed hydrogen storage at either 350 or 700 bar. Batch production of the B-Class F-Cell began in 2009, and several vehicles are currently on test in Europe and the USA. With no mass production expected until 2013, the likely purchases price remains unknown.

Vehicle Segment: Small Family	**Electric Range:** 250 miles (350 bar)	**Fuel cell:** 93kW PEM
Fuel Economy: 0.98 kgH_2 /100km	**Top Speed:** 105 mph	**H_2 Storage:** Compressed

Honda FCX Clarity

The Honda FCX Clarity is one of the most commercially advanced fuel cell vehicles – available to lease in California since 2007, the Clarity is now available in the US and Japan for £390/month. The philosophy behind the FCX is to produce zero-emissions with as close to a 'normal' driving experience and styling as possible. Hydrogen fuel economy equates to around 100 mpg. Although hydrogen availability remains a problem, London plans six filling stations by 2012.

Vehicle Segment: Large Family	**Range:** 240 miles	**Fuel cell:** 100kW PEM
Fuel Economy: 1.0 kgH_2 /100km	**Top Speed:** 100 mph	**H_2 Storage:** Compressed

Source: Descriptions and data supplied by Next Green Car (www.nextgreencar.com)

Even though Element Energy does not explicitly complete the life cycle per km comparison, it is instructive to compare its estimate with the latest figures for new car CO_2 emissions. Using the latest data for average new car emissions in the UK of 145 gCO_2/km (SMMT, 2010), and adding a 15% real-world correction as used by Defra (Hill, 2009), plus an additional 15% for upstream fuel production emissions (SMMT, 2009), the average life cycle for new cars is approximately 192 gCO_2/km. This implies a reduction in life cycle CO_2 emissions of around 48% – which is broadly in line with estimates made by Arup and Cenex (2008) of 'well-to-wheel' emissions reductions of 32–38%.[7]

However, both reports also highlight that larger carbon reductions are likely as the UK grid continues to decarbonise as now legislated. The Arup and Cenex study quantifies this improvement based on the projected carbon intensity of the grid and predicts average life cycle emissions for a BEV in 2020 of only 56 gCO_2/km,[8] representing an emission reduction of around 60%.[9] These figures are consistent with those from E4tech (2007) which predict that BEVs will have the potential to reduce life cycle CO_2 emissions by between 50% and 80% (depending on the methods of electricity generation employed).

Assessing the possible impact of the large-scale deployment of BEVs on UK emissions, Element Energy considers a scenario for 2030 in which 16 million BEVs account for 45% of total car-miles travelled, and estimates a potential CO_2 reduction of 16 $MtCO_2$/yr (megatonnes of carbon dioxide per year) – representing 15% of 1990 road transport CO_2 emissions (and 30% of 2030 baseline emissions).[10] For comparison, in two similarly scaled UK scenarios constructed by Arup and Cenex (named 'high-' and 'extreme-range', indicating the scale of deployment of BEVs and PHEVs),[11] the estimated annual carbon reductions for 2030 are in the region of 9.5–19.3 $MtCO_2$/yr (representing 9–18% of 1990 road transport CO_2).

The life cycle comparisons by Element Energy and Arup and Cenex raise two important issues with regard to assessing the future impact on emissions. First, while both reports base their modelling on the continuing decarbonisation of the national grid, there remains some uncertainty as to how rapidly low-carbon electricity generating capacity (including renewables and nuclear) will be deployed. That said, some (limited supply) renewable electricity tariffs are currently available to UK consumers.

7 Based on current UK electricity mix with a marginal CO_2 factor of 0.43kg CO_2/kWh, current BEV lifecycle emissions of 106 gCO_2e/km, baseline lifecycle emissions of 172 gCO_2e/km (petrol) and 156 gCO_2e/km (diesel).

8 Total greenhouse gas emissions per unit distance are expressed in terms of grams of CO_2 (equivalent) per km, gCO_2e/km.

9 Based on 2020 baseline lifecycle emissions of 144gCO_2e/km (petrol) and 130gCO_2e/km (diesel).

10 Based on an average non-marginal grid carbon intensity of around 0.14 $kgCO_2$/kWh. If marginal generating plant is used, the projected CO_2 savings are reduced to 5.0–8.5 $MtCO_2$/yr, the scale of the reduction depending on whether home-based BEV recharging times are uncontrolled or managed through the use of 'smart meters' and/or other incentives (see Section 4.2).

11 The 'high range' scenario assumes that 3.3 million BEVs and 9.9 million PHEVs are in use by 2030. The 'extreme range' scenario assumes that 5.8 million BEVs and 14.8 million PHEVs are in use by 2030.

Second, the last few years have seen a significant improvement in the average fuel economy of new petrol and diesel cars, as consumers and manufacturers have responded to both the peak oil prices in 2008 and the subsequent economic downturn (see Section 3.2). With the additional impact of new European CO_2 legislation for new cars (discussed in Section 5), it now seems likely that emissions from new cars will continue to fall at a faster rate than during the previous decade. As acknowledged by Arup and Cenex, 'faster improvements in the efficiency of internal combustion engines (ICEs) would reduce, though not entirely remove, the scale of carbon benefits arising from a switch to electric vehicles (EVs) in 2020/30'.

To quantify the emissions benefits offered by current BEVs against an improved baseline, a life cycle comparison can be made with the most fuel-efficient conventional models currently available in 2010 (such as the VW Golf BlueMotion, which has tailpipe emissions of 99 gCO_2/km and is in the same class as the Nissan LEAF). Using a 99 gCO_2/km model as a comparator, Element Energy's estimated life cycle carbon benefit for a BEV is halved to around 24%.

While a full assessment of non-carbon impacts of BEVs is also well beyond the scope of this review, the report by Arup and Cenex is instructive in highlighting the broad range of positive and negative impacts of electric vehicles (Arup & Cenex, 2008). Although the report concludes that BEVs offer significant climate change benefits, reduce noise pollution, and have fewer resource depletion impacts due to reduced use of fossil fuels, the authors also note that BEVs can

increase levels of air pollutants, which leads to higher rates of acidification, and may actually increase the potential impact on human health in areas where resources (such as lithium) are extracted for battery production.[12]

Taken overall, and given that current road transport is responsible for significant emissions of nitrogen oxides and particulate matter,[13] the impact on human health is likely to be reduced within urban areas, well away from the centres of battery production, due to the fact that most ULCVs are zero-emission at the point of use.

While the UK literature concerning the environmental impact of PHEVs and FCVs is less extensive,[14] E4tech (2007) has conducted a review which concluded that PHEVs have the potential to reduce life cycle CO_2 emissions by 40–50% compared with conventional vehicles. Using data from a real-world comparison of 'conventional' hybrids and plug-in hybrid conversions placed in the public domain by Google.org, Ecolane also estimates a reduction in lifecycle greenhouse gases of 35–45% for PHEVs compared with a conventional petrol vehicle (Lane, 2010, unpublished).[15] Although estimates for FCVs are more speculative owing to the fact that the technology is less developed, E4tech projects carbon reductions for them of around 50–80% on a life cycle basis (depending on the primary fuel used).

2.2 Economic considerations

Due to higher production costs, the purchase price of most commercially available ULCVs is higher than that of conventional vehicles. Although a direct comparison with a petrol or diesel equivalent model is often difficult,[16] as a general rule, the cost differential varies in line with the level of drive-train electrification, from around a 10% premium for a full HEV, 30%+ for a PHEV with a 20-mile electric range, to (until recently) at least a doubling of capital costs for a BEV (HM Treasury, 2007; Arup & Cenex, 2008).

For HEVs, as much as half of the price premium is due to the cost of a battery that is able to deliver energy in high power bursts. Based on data from the Toyota Prius, which uses a nickel-metal hydride battery, figures from Deutsche Bank maintain that current 'power batteries' cost £600–£1,000/kW (Deutsche Bank, 2008). For BEVs and PHEVs, which use 'traction' or 'energy batteries'

12 The sourcing of lithium remains a highly charged issue, owing to the level of reserves and the local impacts on human health in areas where lithium is mined (Carroll & Schipani, 2009).
13 The Environmental Audit Committee (2010) maintains that air pollution reduces UK life expectancy in the UK by an average of seven to eight months, with up to 50,000 people dying prematurely due to poor air quality.
14 It should also be noted that the 'electric-only' range of plug-in hybrid vehicles considered by the literature varies widely.
15 Analysis is based on the relative fuel economy data results from a seven-week comparison trial which included the (converted) Ford Escape and Toyota Prius MkII PHEVs (www.google.org/recharge/).
16 There only a few examples of conventional and electric versions existing within the same model range.

capable of delivering energy for long durations, the battery systems represent a larger proportion of additional costs. Using Committee on Climate Change figures cited by Lytton (2010) of around £650/kWh, a small BEV or PHEV requiring a 16 kWh battery would currently cost at least £10,000. It is estimated that battery costs will have to reduce by a factor of four before BEVs will are able to compete with conventional vehicles on price.

It is, however, important to bear in mind that whereas the production costs of hybrids are now well established (following a decade of commercialisation), the costs of future ULCV types remain largely unknown. For BEVs, this is due to the uncertainty as to useful battery life, the impact of volume demand on battery innovation (which could cut production costs dramatically), and future material costs (e.g. that of lithium). (For FCVs, as many of the on-board systems remain at the pre-production stage, cost projections are more academic.)

It is also the case that in the first stages of commercialisation, purchase prices are often set by the market rather than dictated by production costs. In the same way that Toyota initially sold the Prius at a loss to gain market share for hybrids (English, 2007), BEV manufacturers are currently adjusting their prices in readiness for 2011, a year that is likely to be a crucial year for BEV market uptake. For example, in August 2010, Mitsubishi reduced the price of the i-MiEV from £38,699 to £28,990 (£23,990 when the Plug-in Car Grant is taken into account – see Section 5) (Next Green Car, 2010a).

This followed the announcement by Nissan that the new LEAF was to be priced at £28,350.In contrast to their higher purchase costs, ULCVs offer the potential to significantly reduce running costs. At current energy prices, their fuel costs are significantly less than those of conventional petrol or diesel vehicles, due in part to electricity not being taxed as a transport fuel. For example, driving a BEV for 10,000 miles during the course of a year could reduce fuel costs by around £800 compared with a conventional car.[17] Unforeseen battery problems aside, analysis also suggests that non-fuel-related operating costs (such as maintenance) will also be lower for electric vehicles (Deutsche Bank, 2008).

However, although the low running costs offered by BEVs (and other ULCVs) are an important consideration for potential owners, there is extensive evidence that consumers tend to discount future fuel savings (and fuel costs in general) and are more influenced by the ‘up-front’ purchase price.[18] ULCVs pose an interesting dilemma for potential users – gaining access to state-of-the-art vehicle technology that can reduce running costs and emissions requires a significant increase in capital outlay. This adoption barrier will be discussed in more detail in Section 3.

17 Figures taken from Next Green Car and based on an annual mileage of 10,000 miles, and typical fuel costs for a diesel car of 10p per mile and a battery electric car of 2p per mile.
18 According to the King Review (HM Treasury, 2007; 2008), consumers tend to have very high discount rates, possibly as high as 60%.

2.3 UK market potential

'Predictions of growth in electric mobility, and the potential for road transport CO_2 reductions, that are based only on technological roadmaps have limited validity.' *(Skippon, 2010)*

Current BEV and HEV owners are broadly defined by the 'innovator' and 'early adopter' market segments. First defined by Rogers (1962), the innovators are the first individuals to adopt a new product, and typically represent the first 2.5% of the market. They are generally more willing to take risks than the average consumer, are wealthy, young, have high social class, are well educated and are pro-technology. The early adopters, who represent the next 13.5% of market share, have much in common with innovators, but tend to adopt new technologies for more pragmatic reasons.

Transport for London has invested much effort in identifying the early market segments for BEV and HEV users in the capital (Girard, 2010). Using market segmentation methods and demographic data, they have identified three key London-specific early market groups which they name as: 'Global Connectors' (wealthy, single people living in the centre of the city); 'Cultural Leaders' (who live in suburbs and work in central London); and 'Corporate Chieftains' (senior managers who own large suburban properties). It is reasonable to suppose that these market segments will continue to play a disproportionately large role in the adoption of all future ULCV types.

In contrast to this detailed understanding of early adopters, although there is general agreement that mass-marketing of electric vehicles is feasible, no agencies are able to predict with any confidence the rate or final extent of UK market penetration by ULCVs. However, two approaches that have been adopted are to estimate potential market size based on demographic data, and to construct market development scenarios.

For example, analysing data from the National Travel Survey (of trip patterns and trip distance), Element Energy estimates that with today's BEV technology (based on a 70-mile usable range),[19] up to 50% of total UK car-km could be achieved by BEVs under a 'home charge' dominated scenario (requiring no additional infrastructure) (Slater et al., 2009). The contribution rises to over 60% if on-street overnight charging facilities were to be deployed, or 80% if vehicles are developed which have a 125-mile usable range.

Considering the market potential of PHEVs, the analysis also suggests that if all UK cars were PHEVs with an electric range of 20 miles, around 50% of all car-miles could be completed in electric mode, increasing to around 70% for a vehicle with 40 miles electric-only capability.

Element Energy identifies commuting as the trip purpose most suited to BEV use in the UK. Not only does commuting account for around 25% of total annual car miles, but around two thirds of commuting trips are less than ten miles long; furthermore, and most significantly, they are routine journeys for which the driver knows what to expect with respect to distance, route, congestion, road conditions and parking. Deploying workplace recharging facilities would lead, concludes Element Energy, to a significant increase in the number of commuter miles which could be covered using BEVs.

The report by Arup and Cenex (2008) constructs four scenarios of BEV and PHEV adoption –'business-as-usual', 'mid-range', 'high-range' and 'extreme-range' – to reflect vehicle costs, level of support, incentivisation and market demand. While the 'business-as-usual' scenario leads to zero growth in the market for ULCVs, the 'mid-range' scenario (which assumes whole-life cost parity for all drive-trains by 2015), 2.5% of all cars are plug-in by 2020 and 12% by 2030. Under the 'high-range' scenario (in which the UK is a world leader in ULCV manufacture), 4.9% of all cars are plug-in by 2020 and 32% by 2030. In the 'extreme-range' scenario, 10% of all cars are plug-in by 2020 and 60% by 2030.

While acknowledging that any forecast beyond 2012 is 'highly speculative', with the objective of projecting future lithium demand, Deutsche Bank (2008) forecasts that EVs (of all types, including HEVs) will represent 20% of new vehicle sales in the US and 50% of Western European sales by 2015, the vast majority being hybrids (including 'micro', 'mild' and 'full' hybrid types).[20] By 2020, it estimates that EV penetration rates could increase to 49% in the US and 65% in Europe; these percentages would include, in the US, 2% BEVs and 5% PHEVs, and, in the EU, 3% BEVs and 2% PHEVs.

19 While a BEV may have a maximum technical range defined by its battery capacity, the actual 'usable range' is limited by two factors: the need to limit over-discharge (which reduces battery life), and the reluctance of users to push BEVs to their range limit for fear of running out of energy.

20 Definitions of 'micro', 'mild' and 'full' hybrids are given in Lytton (2010: 18).

The European agency Transport & Environment (T&E) concurs with the forecast by Deutsche Bank that, in the short term at least, hybrids will continue to penetrate global markets more quickly than plug-in vehicles (Dings, 2009). As part of its review of ULCV scenarios by the International Energy Agency, McKinsey and Greenpeace, T&E takes the position that, as new technologies usually take ten to twenty years to achieve 5% of market share, BEVs are unlikely to represent more than 25% of global sales by 2050.[21]

21 The report also cites hybrid market research by the US National Highway Traffic Safety Administration, Global Insight and Deutsche Bank.

3. Consumer Attitudes to Low Carbon Vehicles

'Technology achieves nothing if it is not adopted – consumers must be engaged in order to realise fully the potential for reducing CO_2 from road transport.' *(HM Treasury, 2008)*

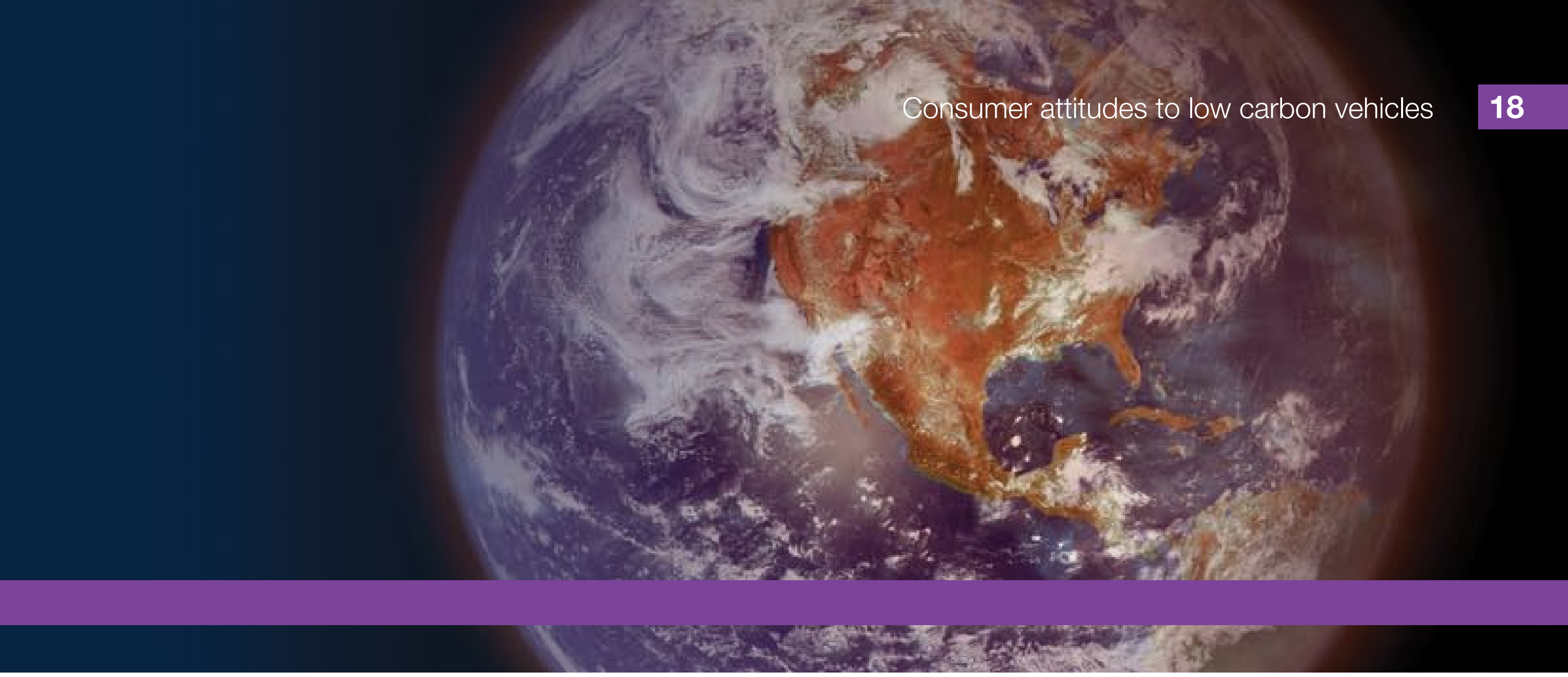
Even though all the findings reported in the following section are useful in assessing consumer attitudes regarding the environment and low carbon vehicles, it should be noted that some are of limited value due to the methodology employed. In particular, while 'stated preference' methodology[22] has its role to play, there is a tendency for this approach to overestimate the potential for actual behavioural change. Furthermore, studies that overly rely on this methodology rarely reveal the more subtle, yet more significant, attitudinal influences which are better able to explain and predict actual car use and purchasing behaviours.

For these reasons, the review draws its evidence more heavily from research which uses revealed preference – or more qualitative methodologies – where available.

3.1 Attitudes to climate change

According the annual Office for National Statistics (ONS) survey, around three quarters of adults are 'very' or 'fairly'

22 Surveys which use 'stated preference' methods ask participants to state their values, and/or to select responses from a list of presented options. In contrast, 'revealed preference' methods infer values from observing actual behaviour.



concerned about climate change (Eleini, 2010).[23] Furthermore, the proportion of adults considering climate change to be one of the top three most important issues facing the UK is about a quarter. In this sense, the UK public is highly engaged with climate change as an environmental issue.

Particular groups with an above-average concern about climate change include those aged 45–54 years, adults with degree-level education, and those with an above-average income. With respect to transport use, above-average concern is expressed by those who use a car less than once a week or never, and those who never fly; below-average concern is expressed by those who use a car every day and those who take flights once or twice a year.

Over half of adults claim to know at least a ‘fair amount’ about climate change, and road transport emissions are the most commonly cited cause of climate change. ‘Emissions from planes’ is mentioned as a cause by around 40%, and the ‘burning of fossil fuels for energy’ is mentioned by around 30% of the population. When asked about particular transport causes in more detail, the public are most likely to choose ‘cars’ (42%), ‘aeroplanes’ (36%) and ‘vans and lorries’ (18%).

Whereas survey respondents believe that industry/business, and to a lesser extent the UK Government, could have a large influence in mitigating climate change, only around 10% feel that their local communities or they themselves (6%) could have a ‘large influence’. Nevertheless, two thirds of adults think that they themselves could have ‘some influence’, with around three quarters saying that they would be prepared to change their behaviour to limit climate change.

Regarding approaches to reducing car emissions, the vast majority of UK adults support the UK Government in persuading people to purchase less environmentally damaging vehicles, although this proportion has reduced from 87% in 2006 to 81% in 2009. A smaller majority (58%) favour individuals trying

23 Broadly similar findings are also reported by a recent report by the Department for Regional Development in Northern Ireland which focused on the public perceptions of car emissions (CSRB, 2009).

to limit their car use for the sake of the environment – a fall from 64% in 2008. In contrast, 37% agreed that people should be allowed to use their cars as much as they like, even if it causes damage to the environment – significantly higher than in 2006 (26%) – with almost exactly the same proportion disagreeing with this point of view.

Support for policies on ‘soft’ measures to encourage alternative modes, such as improved public transport, is far higher than for measures that would increase the cost of car travel. Support for increasing tax on petrol has decreased from 14% of adults in 2006 to 10% in 2009, while support for imposing higher taxes on the most polluting cars (the most popular pricing measure) has decreased from 41% to 37% in the same period.

When the 2009 survey respondents were asked whether they would be prepared to pay more for a car that was less polluting than for an otherwise identical model if they were to buy a new car, 11% of adults said they would be prepared to pay a lot more for a less polluting car, with a further 57% saying they would be prepared to pay a little more. A quarter said they would not be prepared to pay more, while 7% said they would not buy a new car. The results were similar in 2008, but a higher proportion said they would be prepared to pay a lot more in 2006 (16%).

3.2 Attitudes to car choice

When consumers are asked what factors were most important when purchasing their current car, there is strong evidence from a wide variety of sources (using a range of methodologies) that the key factors include (in approximate order of importance): vehicle price, size/practicality, reliability, fuel consumption, comfort, style/appearance, cost of road tax, driving performance, cost of insurance, and brand (Dixon & Hill, 2009; Lehman et al., 2003; Whelan et al., 2000; Angle et al., 2007b; Lane, 2005; Lane & Banks, 2010; Anable et al., 2006).

Of key relevance to this review is very strong evidence from the literature already cited showing that factors that relate most directly to environmental issues have little influence on purchasing decisions. This finding highlights the existence of the ‘attitude–action’ gap – as noted by the King Review already cited: ‘there is a gap between people’s attitudes towards the environment and their actions through their choice of vehicle and the way they drive’.

It cannot be stated too strongly that the finding that environmental issues have little direct impact on car purchase decisions is very robust. In a 2007 survey of motorists conducted by the British Market Research Bureau (BMRB) for the DfT’s Climate Change Campaign (Angle, 2007a), environmental impact ranks 13th in order of importance among factors when choosing their current car – and has the same rank with respect to future car purchases.

The issue here is not that environmental issues are of no importance, but rather that other key issues (e.g. vehicle price, vehicle size, comfort, safety) are, or become, *more important* to consumers at the point of purchase. Research conducted by Ecolane & Sustain also reveals that, even in cases where environmental issues are seriously considered by car buyers, lower emission benefits are often seen as a ‘bonus’ once the primary purchasing objectives have been attained.

For reasons outlined at the start of this section, the significance of car buyers’ attitudes to environmental issues (in the sense of influencing behavioural change) is likely to be even less than that indicated by stated preference research. For example, in a Department for Environment, Food and Rural Affairs’ 2007 survey (Defra, 2007), over 50% of respondents recognised that ‘using a car less’ and/or ‘using a more fuel-efficient car’ would contribute to reducing the UK’s impact on climate change if ‘most people in UK were prepared to do them’ – however, only 12% acknowledge that ‘a lot’ or ‘quite a lot’ of people would actually adopt these particular behaviours.

It could be argued that, because fuel economy is rated as an important issue, car buyers are indirectly interested in a car’s environmental performance. However, the evidence does not support this assertion for at least two reasons. The first is that most consumers do not appreciate the importance of improving fuel economy as a method of reducing carbon emissions – qualitative research conducted for the LowCVP (the Low Carbon Vehicle Partnership) finds that only around half of participants (at most) have an understanding of the link between fuel economy and CO_2 emissions (Lane & Banks, 2010).

The second reason, highlighted by results from the BMRB survey (Angle, 2007b), is that whereas ‘fuel efficiency’ is ranked the third most important factor when buying a car, ‘impact on environment’ is ranked tenth suggesting that fuel economy conveys non-environmental information to car buyers; namely, it is used to gauge fuel costs. As noted by Gärtner (2005: 23): ‘Fuel economy and environmental impact are in general no major factor in vehicle purchase decisions… Fuel consumption is mostly only important because of the cost, but not to environmental issues’ [sic].

Despite the low level of consumer understanding of fuel economy and emissions, it turns out that the concept of fuel economy plays a number of important roles for car buyers. First, while most UK motorists are unable to benchmark levels of CO_2 emissions, they are more able and willing to estimate their car's fuel economy in 'miles per gallon' (Lane & Banks, 2010). A measure of fuel economy, therefore, provides a context within which cost, and even proxy environmental impact, can be simply gauged.

Second, fuel economy tends to be traded off with vehicle size – once a segment has been selected, few car buyers are motivated to search for fuel-efficient models, as they tend to underestimate the span in fuel economy performance within a vehicle class. Third, fuel economy is also traded off against vehicle price. Many car buyers are of the opinion that fuel-efficient cars tend to have a price premium – either because they involve new technologies (such as hybrids), or because (so consumers believe) manufacturers artificially increase the prices of these models. Alternatively, model ranges which improve fuel economy by lowering specifications often have poor symbolic value – see Section 3.5.

The combined impact of these attitudes is to limit the flexibility of consumers when it comes to considering more environmentally friendly models, i.e. improved conventional or new vehicle technology. Instead, most consumers restrict their options, believing that the only route to better fuel economy is through a smaller car, a smaller engine, or switching to diesel. While figures cited by the King Review confirm that downsizing by one vehicle class does (on average) improve fuel use by around 15%, the data also reveals a more significant 25% variation within each segment.

That said, even within this restricted set of responses, UK car buyers are changing their purchasing habits. In response to the fuel price peaks in 2008, followed by the global economic downturn, the UK car market has seen a marked shift to smaller, more fuel-efficient cars, with the 'biggest drop in new car CO_2 on record' – falling 3.6% in the second quarter of 2008 and then 5.5% in 2009 (SMMT, 2008; Next Green Car, 2009). During this period, some surveys have also observed that fuel economy has increased in importance during the car purchasing process (e.g. Lane & Banks, 2010).

A similar market shift has been observed in the US. When the price of gasoline reached the symbolic level of $4.00 per gallon in the first half of 2008, this prompted a significant change in driving habits and a preference for fuel-efficient vehicles. In particular, demand for hybrids rose dramatically (Diamond, 2009).[24]

Taken together, the attitudinal research findings reported here suggest that fuel economy, used as a consumer proxy for fuel costs, is driving the UK and US market towards more fuel-efficient models. As a result, tailpipe CO_2 emissions are also being (indirectly) reduced. However, the findings also suggest that the range of consumer responses to increasing fuel prices (and other price signals) could be widened – so increasing both the rate at which conventional fuel economy is improved (through demand), and the rate at which new technologies are adopted.

24 It could be argued that managing fuel price would be an effective way of increasing ULCV adoption. While it has been shown that fuel duty rises do have an impact on consumer behaviour, the effect is relatively indirect and the consumer response to the price signal relatively inelastic. Such a policy has shown itself to be politically unacceptable (cf. Goodwin et al., 2004).

3.3 Attitudes towards ULCVs

> 'Growth of electric mobility doesn't just depend on… technology, but also on how consumers will respond to new [types] of vehicles that have different characteristics to those they are used to.'
> *(Skippon, 2010)*

Before assessing the attitudes of potential and existing owners of ULCVs, it is worth noting that, due to the fast pace of current technological development, research focusing on the attitudes of consumers towards ULCVs becomes quickly dated. The research findings are also country- and region-specific, reflecting local demographics, transport policy and the availability of incentives (such as the London Congestion Charge's Alternative Fuel Discount).[25]

Despite being based on only a small sample, one Ecolane focus group survey is a useful starting point for gauging the public's level of knowledge of ULCVs in the UK (Lane & Albery, 2009). In agreement with other studies, the survey finds that the 'electric vehicle' is the most widely known type of ULCV. While the report notes that few participants are able to explain how electric vehicles work, there is, however, a general perception that battery electric vehicles have a lower level of performance than conventional vehicles, with less acceleration, a lower top speed and a lower range being issues commonly mentioned.[26]

Although the level of technical knowledge about electric vehicles and recharging points is very low, the majority of those questioned in the survey are (surprisingly) confident in their belief that using electric vehicles reduces environmental impact by comparison with conventional vehicles. Not only are most participants aware that BEVs are zero-emission at point of use, but the survey finds that a significant number of participants are also aware of the need to account for emissions from power stations – even after accounting for power-station emissions (of any type), most participants think that life cycle ('well-to-wheel') emissions for electric vehicles are generally reduced.

Regarding the barriers to BEV adoption, a large-scale survey conducted by Element Energy in 2009 asked owners and 'considerers' to assess the disadvantages of BEV ownership. In common with other studies, survey participants list: high vehicle price, limited driving range and poor access to charging points (Slater et al., 2009). The relative lack of vehicle choice and the time required to recharge are listed as moderate barriers. Of less importance are: limited power and performance, and the unfamiliarity and inconvenience of recharging.

Regarding plug-in hybrid vehicles, Axsen and Kurani (2008) also note that the majority of new vehicle buyers in the US have little or no familiarity with

25 The London Mayor has proposed to replace the Alternative Fuel Discount with a Greener Vehicle Discount. If accepted, the Greener Vehicle Discount would provide a 100% discount for cars that emit 100 gCO_2/km or less and meet the Euro 5 standard for air quality (TfL, 2010).
26 None of the participants had direct experience of driving a BEV.

the idea of a PHEV, and may erroneously believe that existing hybrid-electric vehicles (HEVs) can perform the same basic function as a PHEV, i.e., have the ability to be both refuelled by petrol and plugged into an electrical outlet.

The authors observe that this low level of awareness and technical understanding can be viewed as both a constraint and an opportunity. On one hand, unaware consumers may fail to recognise or identify compelling benefits of owning and operating a PHEV, serving to limit the market. On the other hand, the opportunity is that the early PHEV market in the US may be viewed as a blank slate, with little pre-existing understanding of what a PHEV is, or expectations of what it should be.

Although there has been little research regarding the consumer acceptance of PHEVs in the UK, in a study which asked participants to compare BEVs and PHEVs, paired with varying performance characteristics (including electric and liquid fuel ranges), Skippon (2010) concluded that PHEVs are preferred over BEVs (presumably due to the fuel flexibility and lack of range limitation).

Unsurprisingly, the public's knowledge of hydrogen-fuelled FCVs is very low. As described by Roche et al. (2010), the UK Sustainable Hydrogen Energy Consortium Project (2007–2008) showed that the level of knowledge about hydrogen as an energy carrier was at best moderate and variable, and that males, younger age groups, and those with higher incomes tended to know more about the fuel.

The review also details results of the AcceptH2 project (2003–2005), in which several cities hosted hydrogen bus trials through the CUTE (Clean Urban Transport for Europe), ECTOS (Ecological City Transport System) and STEP (Sustainable Transport Energy for Perth) demonstration projects. In particular, the CUTE trial, part of which took place in London, conducted a consumer study that found that awareness of the technologies was very low, with only just over half of all respondents claiming to have heard about hydrogen vehicles.

Roche et al. also report that the French Stor-HY (Hydrogen Storage Systems for Automotive Application) project found a mix of positive and negative beliefs about hydrogen, which pivoted between the idealisation of a 'natural' and 'clean' solution to energy-related problems and safety fears. The authors argue that these polarised beliefs risk becoming embedded in public opinion unless improved communication is used before the commercialisation of hydrogen and fuel cell technologies.

Given the higher capital costs of ULCVs, together with the importance of vehicle price at the point of purchase,

several studies attempt to quantify the extent to which consumers are willing to pay for more expensive, but lower emission, cars. Noting again the limitation of the stated preference methodology used, the trial conducted by Shell and E.ON found that consumers were willing to pay purchase premiums of just over three times the perceived annual running cost savings – when presented a (hypothetical) BEV which offered £700 annual running costs savings, they reported they would be prepared to pay an additional £2,250 (Skippon, 2010).

In a review of US consumers, Kurani et al. (2008) cite several research findings regarding willingness to pay for ULCVs. In one study, 26% of a sample of US car buyers said that they would pay an extra $4,000 (about £2,600) for a PHEV (capable of a 20-mile EV range). A market research study by the Electric Power Research Institute found that, among a sample of 'mid-sized car buyers', 53% were prepared to pay a $3,000 (£2,000) premium for a similar type of PHEV. However, only 16% of these same respondents were prepared to buy a PHEV if the additional cost rose to $9,000 (£6,000). The findings of a Canadian study are broadly in line with this US research; Pollution Probe and Environics (2009) conclude that few car buyers are prepared to pay more than a 15% premium for a PHEV.

While there is less evidence of willingness to pay for FCVs, Martin et al. (2009) report similar levels of acceptable price premiums. Following fuel cell car 'drive clinics', participants reported that they would be willing to pay $4,000 (£2,500) or more for a zero-emission FCV that was similar to their own car. The researchers also note that premiums on operating costs are less tolerated, with around 25% of respondents indicating no tolerance for any increase in operating cost. Operating cost premiums exceeding $1,000 (£650) per year would be unattractive to 75% of the respondents.

Although stated preference studies tend to overestimate the actual levels of 'willingness to pay' for new vehicle technologies, they are useful in gauging the premiums that are likely to be accepted by the first wave of ULCV consumers. At the very least, it can be concluded that, with the current price premiums (as discussed in Section 2.2), the purchase price of most ULCVs remains a key barrier to their adoption by the mass market. Financial incentives are, therefore, likely to be needed to stimulate consumer demand.

3.4 Real-world trials of ULCVs

The findings described in this section again highlight a methodological issue – in this case one that relates to researching consumer attitudes to new types of product (e.g. new types of vehicle). Asking consumers about new technologies of which they have no previous experience can result in misleading responses. More weight, therefore, is given to research that provides this experience as part of the survey design.

In contrast to the low level of knowledge about BEVs, real-world consumer trials of BEVs indicate high levels of consumer acceptance. In particular, acceptance is found to increase during the trials, suggesting that, in general, ULCVs perform better than consumer expectations and challenge their preconceptions.

For example, in the ‘smart move’ trial conducted by Cenex (the Centre of Excellence for low carbon and fuel cell technologies), which deployed four smart ‘electric drive’ two-seaters in a series of locations across the North East, the vehicles exceeded the public’s expectations on all monitored performance criteria (most notably top speed), leading 72% of the drivers to state that they would use an electric vehicle as their regular car, compared with 47% before the trial – a significant increase of 25% (Carroll, 2010). Among the corporate participants, 58% of fleet users were more positive about electric vehicles following on-road tests, and 88% of fleet managers were more positive about incorporating BEVs into their fleets following the trial.

A study by Shell and E.ON, in which 92 employees were given to the opportunity to test drive or short-loan a Mitsubishi i-MiEV, also found that vehicle performance is rated highly following test drives (Skippon, 2010). In particular, acceleration from a standing start and smoothness of acceleration received high scores relative to a conventional vehicle. The reduction in noise also scored well (although results from the Cenex trial were more mixed due to the understanding by users that lower exterior noise raises issues concerning pedestrian safety).

Encouragingly, during the Cenex trial, both the general public and fleet participants in the 20–30 year age group, and those with no prior experience, exhibited the largest shift in attitudes towards electric vehicles. While only 25% of test drivers in their 60s were more positively disposed towards BEVs following the trial, for those in their 20s, the shift was as high as 83% (the figure from the fleet user sample).

Although consumers report that the limited driving range is an important barrier to EV ownership, evidence from both the Cenex and the CABLED trials (Aston University, 2010) (the latter funded by the TSB as one of the winners of its Ultra Low Carbon Vehicle Demonstrator competition) suggest that, in practice, the problem may be overstated. Both trials showed that users were overcautious when planning journeys, implying that the limited range of BEVs is not a crucial barrier.

Analysing data from over 100 trips in the Cenex trial, the maximum journey length undertaken was only 25% of the average usable vehicle range of 62 miles. When driving the BEVs, users tended to overestimate the required safety margin to the extent that 93% of journeys commenced with over 50% battery state of charge – users also modified their driving style when the battery state of charge reduced below 50%.[27]

27 As discussed in Section 2.3, there is a reluctance on the part of users to push BEVs to their range limit for fear of running out of energy.

Regarding on-board driver information and feedback, the driver display in the BEVs tested was rated poorly by participants, leading the trial managers to recommend the need (in general) for more sophisticated on-board range prediction aids to support mass-market adoption. Indeed, just such a display is included in the Nissan LEAF, now available for order in the UK and expecting the first deliveries in early 2011.[28]

It is interesting to note that the potential benefit of low running costs is not reported by participants in the trials. Although the low fuel costs offered by BEVs make whole-life costs appear favourable on paper, the study by Arup and Cenex (2008) notes that private consumers tend to heavily discount future savings – possibly by as much as 60% (cf. HM Treasury, 2007). The result is that the higher capital cost of electric vehicles continues to dissuade many potential purchasers. This issue will be revisited in Section 5.1.

Several US studies also report the reactions of drivers to FCVs (e.g. Martin et al., 2009). In one 'ride-and-drive' clinic held in Northern California, participants were able to test drive a Mercedes-Benz A-Class 'F-Cell' hydrogen FCV. The clinic evaluated the reactions of participants to driving and riding in a passenger FCV, as well as witnessing a vehicle-refuelling event. Results from the clinic were comparable with a previous longitudinal study employing 24 F-Cells which were tracked over a seven-month period.

The surveys found that exposure to hydrogen and FCVs improved perceptions of safety. Whereas 30% of participants entered the study believing that hydrogen was less safe than petrol, following exposure to the vehicle, this proportion had dropped to 7%. The study also found that respondents considered the performance of the vehicle (in terms of acceleration, braking, and handling) to be acceptable. Although the respondents faced greater exposure to range limitations, both sets of respondents considered 250–300 miles as an acceptable vehicle range.

3.5 Symbolic value of ULCVs

> 'Exploring product purchase and use behavior [sic] through understanding what products and their uses mean – or, symbolize – is common in consumer research, but less developed in transportation research.' (Heffner et al., 2007; cf. also Roche et al., 2009)

Although it is true that both quantitative and qualitative attitudinal research has contributed positively to the debate concerning consumer responses to ULCVs, the majority of this research is deficient in one crucial aspect: it is dominated by the framing of the consumer as a 'rational actor'. This refers to the assumption that the consumer will choose options that maximise

28 See www.nissan.co.uk/?cid=pselectricvehicleUK_enelectricvehiclelocuk&kw=Nissan_leaf#vehicles/electricvehicles/leaf/leaf-engine/explore/ecodrive.

utility subject to his or her preferences, knowledge, and budget – it leads, for example, to the assumption that car buyers purchase vehicles that incorporate new technologies (such as hybrids), when whole-life costs are reduced.

However, Heffner et al. (2006) make two observations about the importance of semiotics[29] to car ownership. First, they note that cars usually symbolise ideas other than mobility. Second, many of these symbols relate to consumer self-identity. By choosing to purchase a particular vehicle, car buyers communicate to others who they are, and in doing so, publicly express their interests, beliefs, values, and social status.

The fact that ownership of a particular model is a powerful signifier of social and personal identity is well accepted by manufacturers. Indeed, car companies invest a great deal of resources in building their brand so that their customers feel they are buying a product that is more than just a means of getting from ‘A’ to ‘B’.

The importance of symbolic values is also observed in a LowCVP survey that focuses on the attitudes of car buyers to environmental issues and fuel economy (Anable et al., 2008). In a series of interviews with car buyers, participants often make reference to the symbolic aspects of their purchase and how the car’s image is an important factor in the decision-making process. One of the observations of the report is that potential environmental benefits (such as high fuel economy) are rejected if they are considered to be incompatible with the buyer’s identity.

The survey also finds that the most fuel-efficient models have weak symbolic associations. For example, respondents rarely make explicit linkages between good fuel economy and desirable signifiers such as modernity, innovation and technological development. Instead, fuel economy is generally spoken about in more mundane terms – as an important feature of car choice required to reduce the cost of motoring.

Symbolic aspects can, therefore, override the more ‘rational’ calculations related to fuel efficiency or even the utility of the vehicle. Given that the notion of a ‘low carbon car’ is usually associated with small cars, which in turn are generally considered to be inferior to larger more comfortable models, low emission cars are similarly categorised as something that respondents must reluctantly accept. Noting one such element of compromise, the BMRB survey already cited found that 34% of participants agreed with the statement: ‘you have to sacrifice style if you want your car to be environmentally friendly’ (Angle et al., 2007a).

Any car can have symbolic value, but the evidence suggests that symbolism is particularly strong for vehicles that use new types of technology. In a study

29 Semiotics refers to the study of signification and communication, signs and symbols.

of 25 US households that purchased a Honda Insight, Honda Civic Hybrid, or Toyota Prius, Heffner et al. (2007) investigated the symbolic meaning of HEVs. The qualitative study found that the symbolic values associated with hybrids are multiple and include (in a US context): ‘preserving the environment’, ‘opposing war’, ‘saving money’, ‘reducing support for oil producers’, ‘owning the latest technology’ and demonstrating ‘individualism’.

Even ‘saving money’ can have symbolic value, rather than be a rational-actor response. Several US studies observe that although HEV and PHEV households articulate their vehicle choice in terms of cost savings, few actually calculate potential cost savings or compare lower operating costs with initial purchase prices to determine a payback period (Kurani et al., 2008).[30] Instead, most households act on *symbols of savings* – such as is provided by the real-time fuel economy display provided by most HEV and PHEV models, which often show a reading of 99.9+ ‘mpg’.

These US studies particularly highlight the symbolism of operating PHEVs in EV-mode, which can be linked to the idea of ‘freedom from petroleum’ – a symbol which can be transferred to driving a BEV. In one survey, PHEV owners report the positive feelings associated with ‘getting off gasoline’, which is viewed as an ‘old technology’, ‘dirty’ and ‘polluting’, while driving in all-electric mode is associated with a new aesthetic and described using words such as ‘quiet’, ‘smooth’ and ‘silent’.

The author is only aware of one UK project investigating consumer responses to ULCVs that has assessed their symbolic value. Using multiple-response questions of the form ‘If you saw someone driving an electric vehicle, what would it say about them as a person?’, the study by Shell and E.ON concludes that BEVs have symbolic as well as functional value to some consumers (Skippon, 2010).[31] In particular, the study finds that driving an EV is associated with above average ‘openness’, ‘conscientiousness’ and ‘agreeableness’ – findings, the authors note, which are consistent with survey results from the public research university UC Davis concerning the symbolism of HEVs in California.

In contrast to these positive symbols, other research points to a potential negative value for BEVs. Given the strong association of ‘freedom’ with ‘the car’, there is some evidence that BEVs, with their current range limitation, may negate the sense of spontaneity currently associated with vehicle ownership – the ability to just jump in the car and go ‘wherever you want’ (Pollution Probe & Environics, 2009). It remains to be seen which symbolic values will be attached to ULCVs as the market evolves – indeed, how ULCVs are experienced and valued may be important factors which ultimately determine their success.

30 Furthermore, those drivers who did analyse their operating expenses discovered that their PHEVs delivered only modest cost savings (one owner of an independent conversion estimated that he had saved $8 in 3,000 miles of driving!).

31 Five domains of the Five-Factor Model of personality were tested, which included: ‘openness’, ‘conscientiousness’, ‘agreeableness’, ‘extraversion’ and ‘neuroticism’.

4. Developing New Refuelling Infrastructure

'…existing UK power grid capacity will be sufficient… to support a significant expansion of plug-in hybrid and electric vehicle use and is therefore not a constraint on implementation.' *(Neville Jackson, Ricardo group technology director in Next Green Car, 2009b)*

A key issue for the mass-market adoption of innovative vehicle types is the availability of new fuels – which in the case of ULCVs means either electricity or hydrogen.

In most scenarios envisaged for the deployment of hydrogen FCVs, a dedicated refuelling network has first to be developed before any shift to fuel cell technology can occur (Dunn, 2002). Regarding the initial level of coverage required, research suggests (for hydrogen at least) that new fuel needs to be available at between 5% and 20% of fuel stations for widespread adoption to occur (HyWays, 2007). Results from a fuel cell 'drive clinic' suggest that most respondents were willing to travel five minutes out of their way to find fuel, and a sizeable proportion appeared willing to drive at least 15 minutes (Martin et al., 2009).

In the case of BEVs, there remains some debate about the extent to which the existing infrastructure (as opposed to dedicated on-street recharging points) can accommodate vehicle recharging and the needs of the first owners of electric vehicles. Although the adoption of plug-in hybrid vehicles is

less dependent on the availability of electricity or other non-standard vehicles fuels than is the adoption of BEVs, there is also evidence that adopting different refuelling cycles (electric, liquid fuel or ‘blended’) can have a significant impact on emissions, costs, and consumer attitudes (Axsen & Kurani, 2008).

4.1 Planning infrastructure provision

Element Energy uses findings from the ONS Omnibus and English House Condition surveys which suggest that around 80% of UK car-owning households already have access to a garage or other off-street parking facility (<50% urban, 70% sub-urban, and > 95% rural) (Slater et al., 2009). The implication is that the existing electricity supply accessed through standard (13A, 240V) home-based sockets is sufficient to provide ‘slow’ charging facilities for a significant switch to electric vehicles.

In a major survey of over 2,000 car-buying households, a recent estimate by UC Davis also concludes that at least half of such households in the US have the potential to recharge an EV at home – and notes that this figure is between one-and-a-half and three times larger than previous estimates (Axsen & Kurani, 2008).

Alongside home charging, Element Energy identifies UK workplace charging as an important way to provide additional recharging for a large-scale electric fleet. Not only does commuting contribute most to overall UK mileage, accounting for around a quarter of all car miles (see Section 2.3), but cars used for commuting spend on average around seven hours parked per day, long enough to provide a full recharge for most plug-in electric vehicles.

Together with the observation that the average time spent parked during non-commuting trips is less than 2.5 hours, Element Energy also concludes that the existence of a publicly accessible network of ‘slow’ charging points would have limited additional benefit for the adoption of an electric fleet, and cites evidence from France which suggests that the provision of a significant number of recharging points nationwide (including 200 points at 51 locations in Paris) has had little impact on BEV adoption.

This position is supported by the Mitsubishi i-MiEV trial conducted by Shell Global Solutions and E.ON Engineering (Skippon, 2010). Following real-world experience of BEVs, participants stated a stronger preference for home and workplace charging, and were less inclined to use charge points located at supermarkets or sited on-street.[32] BMW Group (2010) also report that, in the MINI E trial in Berlin, 56% of participants never used any of the 33 public access charging points across the city, preferring to recharge at home.

It is interesting to contrast this position with the significant resources already committed to the development of an on-street recharging network by national and local government (see Section 5) – whereas a standard 'off-street' charge point costs at little as £50 to install and virtually nothing to maintain, even at volume, public-access 13A or 16A charge points each have capital costs of around £2,500 and maintenance costs of around £200 per year (Slater et al., 2009). 'Fast' charging points, many of which are capable of halving recharging times, and 'rapid' charge units, which can recharge EVs in minutes, are even more expensive, with capital costs starting at around £40,000.

However, as noted by Arup and Cenex (2008: 38), it may be the case that publicly accessible charging infrastructure is necessary from an attitudinal perspective to encourage BEV and PHEV adoption: 'For practical and peace of mind reasons the abundance of public charging points will be important.' The central questions here are: on what scale are public access charging locations really required (in terms of their level of utilisation), and to what extent should resources be focused on supplying them in sufficient numbers to provide psychological reassurance?

With regard to the ability of the national grid to support a large scale EV fleet, the report by Arup and Cenex concludes that there is sufficient generating capacity to cope with the projected adoption of electric vehicles – providing there is some management of demand which promotes vehicle charging at off-peak periods, where there is currently a surplus of capacity.

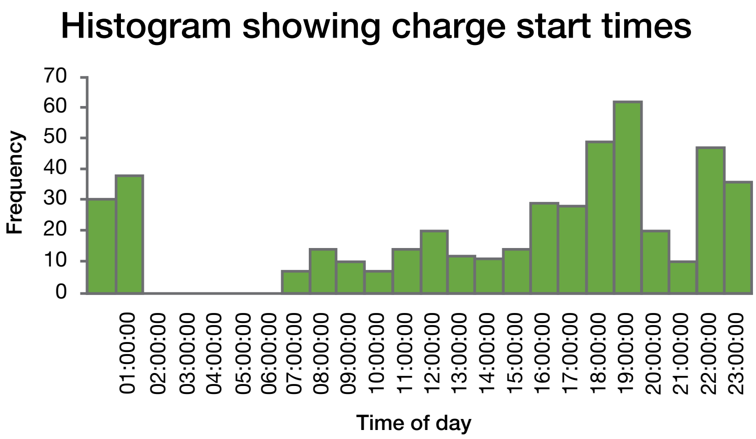
Assuming sufficient demand management is in place, Arup and Cenex estimate, using their 'mid-' to 'high-range' EV adoption scenarios (in which 12–32% of all cars are BEV or PHEV), that generating capacity would only need to increase by 2–4% by 2030 – even the 'extreme' scenario (with 60% penetration) would require a modest 8% increase. There is even evidence that promoting off-peak utilisation of the grid would increase overall generating efficiencies as partly loaded plants are increased to full-loading – with a predicted efficiency gain of around 5%.

32 Payment for charging using credit/debit card and using the existing home electricity bill were also preferred to setting up a separate account with the energy provider or using cash.

Modelling by Ricardo confirms this general finding. Assuming a 10% UK market penetration of PHEVs and BEVs (representing 3 million light-duty vehicles), their study showed a daily peak increase in electricity demand of less than 2% (approximately 1GW) for the scenario of uncontrolled domestic charging – the 'worst case' in terms of peak demand (Next Green Car, 2009b).

However, while the existing capacity and national transmission network is sufficient to cope with increased demand, there is much evidence from a range of sources that local distribution networks will require strengthening where they are already close to capacity. This is due to the early evening peak loading that is predicted to occur should EVs be adopted in significant numbers. As demonstrated by data from the CABLED BEV trial, a significant number of BEVs (25%) return home and commence recharging in the early evening between 6 p.m. and 8 p.m. (Aston University, 2010) – see Figure 7.

Figure 7: Observed home charge start times (CABLED trial)



Source: Aston University (2010)

Evidence that this is an international problem is provided by a US study of 40 households that participated in an extended PHEV demonstration project in Northern California, which reports that in the absence of any pricing signals or tariffs, on weekdays, households tended to plug in their PHEVs in the early evening, usually upon arriving home (Davies & Kurani, 2009). The report identifies an increased risk of peak loading on weekdays, in the early evening from 5 p.m. onwards. Another US study of potential PHEV users also concludes that 'unconstrained recharging among PHEV buyers may exacerbate current peak electricity demand…' (Axsen & Kurani, 2008: vi).

To analyse this potential problem in detail, Element Energy considers three UK charging scenarios – 'home slow-charging', '80–20 home-opportunistic charging' using 80% slow and 20% fast charge points, and '60–40 home-opportunistic charging' using 60% slow and 40% fast charge points (Slater et al., 2009). Assuming a 1% growth in loads until 2030, the analysis considers: steady-state customer profiles, steady-state voltage regulation, steady-state voltage unbalance, thermal loading, network load losses and other power quality issues such as harmonics, voltage fluctuations and flicker.

The Element Energy analysis concludes that the only issue of concern is the transformer thermal loading of the 11/0.4kV distribution transformers used as part of the existing low voltage distribution network. During peak loading conditions (autumn/winter; 5 p.m.–9.30 p.m.; home charging), loading is estimated at between 550–690 kW, which exceeds rating by 10–35%. The analysis concludes that under all scenarios tested, with the existing tariff structure, '…network reinforcement would be required to accommodate the additional electrical load due to BEV/PHEV charging'.

Should demand management not be possible (see next section), and assuming that 30% of the distribution transformers in the UK would need to be replaced at a cost of £20,000–£30,000 per transformer, Element Energy estimates that the associated costs of accommodating 15.9 million BEVs/PHEVs would be in the region of £2.6 billion to £3.9 billion.

4.2 Managing recharging demand

An alternative to reinforcing the distribution network is the adoption of direct or indirect Demand Side Management (DSM) techniques which have the potential to facilitate high penetrations of EVs without the need for costly network reinforcement. DSM will inevitably require the development of the 'smart grid' and 'smart meters', which integrate information and communications technologies (ICTs) with the electricity supply (DECC, 2010).

'Smart grids' allow the real-time flow of information across the grid and enable more interaction between suppliers and consumers. The hope is that they will promote the development of a more distributed electricity network – one in which consumers can generate their own electricity and feed in any excess to the grid – as well as one with more supplier and user control. In the case of plug-in electric vehicles, the advent of 'smart meters' will enable suppliers to introduce time-based tariffs, and allow users to shift their demand to cheaper, off-peak times.

While analysis by Element Energy shows that, in the worst-case UK scenario (winter; home slow-charging; standard tariff structure), the peak evening loading of the distribution network exceeds its rating by 35%, the introduction of a dual tariff (which would require the use of a 'smart meter') can significantly reduce the extent of peak loading. In assessing the impact of a dual tariff, where 65% of the customers charge their EVs after 11 p.m. in order to take advantage of the reduced electricity rates, Element Energy concludes that overloading of the distribution transformer can be reduced to less than 20%, which might under certain circumstances be acceptable to the local Distribution Network Operator.

Although it is not a major issue, one US study notes a potential trade-off between DSM and emissions reductions. In the study by Axsen and Kurani (2008), three charging scenarios ('unconstrained', 'universal workplace', and 'off-peak only') were analysed to represent potential boundary conditions on PHEV driver recharge patterns, and predict trade-offs between the timing of PHEV electricity use and the extent of potential environmental benefits. The authors conclude that '…pushing vehicle recharging to off-peak hours through charging controls, time of day tariffs or other means could reduce overall electricity used by vehicles' (Axsen & Kurani, 2008: vi).

In addition to managing demand, 'smart grids' and 'smart meters' would (in the longer term) also allow the development of 'vehicle-to-grid' (V2G) and/or 'vehicle-to-house' (V2H) options. V2G would enable BEVs to be used (with the owner's permission) as energy storage devices for the national grid. In their scenarios for 2030, Arup and Cenex (2008) estimate that a large fleet of BEVs could store up to 15 hours of national storage, representing energy equivalent to 8% of National Electricity Production. Less favourable for the V2G option, however, are concerns that the increased cycling of the batteries would severely reduce their working life – so increasing the cost of battery ownership. One estimate by Arup and Cenex finds that, to use this method of storage, electricity would have to be bought back from the consumer at ten times the commercial rate, which effectively rules out this option out at the present time.

Connected instead to a local network, or directly to the household supply, V2H is more cost-effective from the consumers' perspective and, therefore, a more likely technological option.

One US survey of PHEV owners (albeit using only a small sample) finds that few EV users are interested in generating revenue by selling electricity back to the electricity grid (the V2G option) (Kurani et al., 2008). Most participants who did raise the topic were employees of electric utilities, and viewed V2G as impractical. The one PHEV owner who did express interest in connecting his vehicle to the supply was more interested in the V2H option, and was excited by the possibility of providing electricity to his home during electricity outages. In the US, V2H could be an important selling point for PHEVs.

To complete this section, this review considers three findings from the US which highlight potential attitudinal barriers related to recharging behaviour and certain plug-in vehicle types. The first is that new PHEV users reported that they lacked a sense of 'recharging etiquette' when looking for recharging opportunities away from home (Davies & Kurani, 2009). While some noticed 'EV parking' and recharging spaces, they often reported being unsure as to whether they could park and charge their PHEVs in such EV-denoted spaces. Furthermore, many users also reported being uncertain of the propriety of asking friends, acquaintances, employers, and business owners whether they could 'plug-in'.

The second observation is that, despite the provision by one real-world US trial of a tool to track both petrol and electricity costs, most PHEV users had little or no understanding of how much it cost them to refuel or recharge the vehicle (Kurani et al., 2009). Given that reduced fuel costs are purported to be an important benefit of plug-in electric vehicles, there may be an opportunity here for improving consumer information regarding recharging costs – either through 'smart metering', on-board hardware, or education.

Third, in a BEV survey conducted in New York City, respondents reported difficulties in gaining access to recharging facilities in private parking lots, many of which are located in underground garages (The City of New York, 2010). The PlaNYC project reported the need for more consumer information, including a clear procedure for the installation of recharging equipment, at home or in a commercial garage. Despite the fact that the building stock is very different in the UK, there may be a similar need among prospective BEV and PHEV owners for information about commercially available recharging equipment and the administrative process required to have one installed.

4.3 Future recharging strategies

In an interesting paper about the deployment strategies for new fuelling infrastructure in the Netherlands, Huétink et al. (2005) address the impact of initial refuelling infrastructure and the expected diffusion pattern of new vehicle types. Using 'agent-based modelling',[33] the research investigates the effect

33 An agent-based model consists of agents, rules and environments. In this model, agents are consumers and refuelling stations. The rules are the mechanisms by which consumers and fuel stations decide whether or not to adopt hydrogen. The environment in which the agents reside is a simplified representation of The Netherlands.

of different spatial arrangements of new refuelling locations on the adoption decisions of consumers, which in turn depend on the 'innovativeness' of the consumer and the perceived attributes of the new vehicle technology.

Regarding the initial location of fuel stations, for the 8% and 18% fuel availability strategies the research finds that a nationwide deployment strategy leads to a higher rate of diffusion than an urban-focused strategy, regardless of the social network structure. This implies that, to promote a new fuel and vehicle technology, pursuing maximum geographical coverage with initial fuel stations is a more effective deployment strategy than focusing on densely populated areas which are only able to reach a limited number of consumers at each individual station.

A more radical infrastructure solution (than any of the strategies so far discussed) is 'battery exchange' whereby, at designated stations, empty or partially-spent batteries are physically exchanged for ones which are fully recharged. While this option offers a refuelling experience which has much in common with conventional liquid refuelling (with regard to time and 'convenience'), the technology requires the standardisation of EV design and increases the risk of discharge due to the making and breaking of electrical connections.

Despite the technical challenges, the main proponent of this option, Project Better Place,[34] has already attracted at least $200 million in venture capital, has entered agreements with Nissan and Renault, and is planning to develop a series of battery swap stations (and more conventional charging networks) in Israel, California, Denmark, Ontario, Hawaii, Australia and Japan. The company's strategy, which is to target high-mileage consumers, relies on a radical market shift to BEVs in contrast to the incremental expectations of most other EV advocates (Slater et al., 2009).

34 Project Better Place website: www.betterplace.com. The company's initial target is to serve 35,000 EVs in 2011 in Israel and Denmark.

5. Policy and Regulation

'By improving the design of fiscal policies… policymakers can be more effective in efforts to reduce carbon emissions on the one hand and demand for oil on the other.'
(German & Meszler, 2010: 3)

Existing and planned UK support for ULCVs takes place within the framework of the European Union's strategy to reduce CO_2 emissions from new cars. This strategy, which consists of three approaches, provides a useful context within which to assess different types of promotional policy for ULCVs (de Haan et al., 2009).

The first approach is legislation – in addition to the long-standing vehicle emissions standards which regulate the air quality emissions from new cars,[35] the European Parliament recently adopted an average sales-weighted new car emission limit of 130 gCO_2/km for 2015.[36] The cap will be phased in over three years: 65% of each manufacturer's newly registered cars must comply by 2012, 75% by 2013, 80% by 2014 and 100% by 2015. A more challenging target of 95 gCO_2/km has been agreed for 2020.[37]

35 European directives have been instrumental in reducing what are known as the 'regulated emissions', which include: carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HCs) and particulate matter less than 10 microns in size (known as PM10). Currently, limits for new cars and light-duty vans must conform to Euro 4 standards.
36 While the average limit is 130 gCO_2/km, manufacturers are set specific limits depending on their fleet's average mass.
37 Manufacturers that exceed targets from 2012 onwards will have to pay a penalty for each car registered, which amounts to €5 for the first gCO_2/km over the limit, €15 for the second gCO_2/km,€25 for the third, and €95 for each subsequent gram.

The second part of the EU strategy is the provision of consumer information – this includes the Fuel Economy Label for new cars, which provides fuel consumption and CO_2 emissions data, and related information including booklets and posters which have to be available at the point of sale. The role of consumer information on car purchasing decisions is discussed in more detail in Section 5.2.

The strategy's third element consists of fiscal measures that are designed to influence purchasing behaviour and car use – these are generally implemented through registration tax, purchase rebates or grants, circulation tax, fuel excise duty and company car tax. While a variety of incentives are in place across the EU, the majority are rated according to CO_2 emissions or fuel consumption (see Table 5.1). In the UK, consumer incentives for conventional low emission vehicles have been in use for around a decade. These consist of graduated Vehicle Excise Duty (VED) which scales with CO_2 emissions,[38] reduced fuel excise duty on low carbon fuels, and CO_2-based company car tax.

Incentives for BEVs (the most widely available type of ULCV) are similarly varied across the European Union and include: purchase grants, exemption from (or reductions in) circulation tax, reduced registration tax, and reduced fuel duty (see Table 5.2). Within the existing UK tax structure, BEVs have been incentivised through exemptions from VED and fuel excise duty, through preferential benefit-in-kind rates for company cars,[39] and through Enhanced Capital Allowances. In 2003, the first London Mayor also introduced incentives for low carbon vehicle technologies (such as BEVs and HEVs) as part of the London Congestion Charge scheme. The scheme's 100% AFD, worth over £2,000 per year to regular commuters driving in the charging zone, has been particularly effective in stimulating demand for new vehicle technologies in London (see Section 5).[40]

38 The current system of graduated Vehicle Excise Duty now ranges from £0 p.a. for band A cars (<=100 gCO_2/km) up to £435 for a band M model (>255 gCO_2/km). Since 1 April 2010, a new 'first-year rate' has also been introduced for all new cars which has a maximum cost differential of £950 in the first year of ownership.

39 From April 2010, BEVs are zero-rated until 2015.

40 As noted in Section 3.3, the London Mayor has proposed to replace the Alternative Fuel Discount with a Greener Vehicle Discount, which would provide a 100% discount for cars that emit 100 gCO_2/km or less and are Euro 5 (TfL, 2010).

More recently, the new Coalition confirmed that a Plug-in Car Grant will be available from January 2011 (DfT, 2010). The grant will provide 25% towards the cost of a new BEV or PHEV, capped at £5,000.[41] The £43 million initiative,[42] which will fund up to 8,600 cars, forms one part of the Government's strategy to support the creation of a UK market and industrial base for ULCVs. Also included in the funding programme is £30 million for developing a network of electric vehicle hubs, called Plugged-In Places, which will provide publicly accessible charging points on-street, and at major supermarkets, leisure and retail centres.

Given the high concentration of EV early adopter segments in the capital (see Section 5.1), London is likely to continue to play a key role in stimulating the adoption of ULCVs nationwide. With the aim of making London the 'electric car capital of Europe', the Mayor plans to introduce 100,000 electric vehicles and install 25,000 EV re-charging points across London by 2015 (Jha, 2009). Initiatives supporting these goals include procuring at least 1,000 Greater London Authority fleet electric vehicles; amending the London Plan to require the installation of new re-charging points in all new developments; guaranteeing exemption of BEVs from the London Congestion Charge; and the co-ordination of EV introduction through the London Electric Vehicle Partnership.

London has also joined other major cities around the world to form the 'C40 Electric Vehicle Network', which has the following aims: to facilitate the deployment of charging infrastructure, to co-ordinate consumer and business purchase incentives for electric vehicles, and to develop plans to mobilise demand for urban EVs by 2013. Several London Boroughs – including Camden, Richmond, the City of London and the City of Westminster – have also taken a lead in supporting the use of BEVs through the provision of reduced-cost residential and on-street parking schemes. Many metropolitan authorities across the UK are also installing on-street charging points, including Camden, which has recently installed London's first public access fast-charging point for commercial EVs.

5.1 The case for purchase 'feebates'

Within the conventional car market, there is much evidence to suggest that VED is not a sufficiently strong price signal to incentivise the purchase of lower CO_2 cars – the adjacent band differentials have (historically) been too small to have had a significant impact on purchasing behaviour (Anable et al., 2008). Although there is no evidence to assess the impact of the exemption of BEVs from VED, the benefit is therefore likely to have been of symbolic, as opposed to financial, value to BEV owners.

41 From 1998 to 2005, the Energy Saving Trust offered 'PowerShift' grants of up to 75% of the additional costs of alternatively fuelled vehicles. The scheme was instrumental in stimulating the then emerging UK cleaner vehicle market; mostly LPG and natural gas conversions and some hybrid electric cars.

42 Whereas the original announcement has earmarked £230 million for the consumer grants, the Coalition have only committed £43 million for the scheme up to March 2012 – a potential budget cut of 80%. The scheme will be reviewed in January 2012 (DfT, 2010).

More effective has been the use of CO_2-based company car tax. Historical data shows that, until the fuel price peaks in 2008, the company car tax system was the main incentive driving the reduction of new conventional car CO_2 emissions. Up to 2008, with a cost gradient of around £10 per gCO_2/km-yr, new company car CO_2 emissions reduced on average by 1.4% p.a., by comparison with a corresponding figure of only 0.9% p.a. for private cars (SMMT, 2007). However, even the incentives offered by the company car tax system have not succeeded in stimulating the market for BEVs or other types of ULCV.[43]

Table 5.1: Selected CO_2-based vehicle taxes in the EU (as of 2009)

EU STATE	METHOD OF CALCULATING ANNUAL CIRCULATION
AUSTRIA	A **first-year registration tax** is calculated as follows: petrol cars: 2% of the purchase price x (fuel consumption in litres – 3 litres); diesel cars: 2% of the purchase price x (fuel consumption in litres – 2 litres),
BELGIUM	**Tax incentives** are granted to private persons purchasing a car that emits <115 gCO_2/km. The incentives consist of a reduction in the purchaser's taxable income under personal income tax: cars emitting <105 gCO_2/km: 15% of the purchase price, with a maximum of €4,270; cars emitting 105–115 gCO_2/km: 3% of the purchase price, with a maximum of €800.
DENMARK	**Circulation tax** is based on fuel consumption. For petrol cars the rates vary from 520 Danish krone (DKK) for cars driving at least 20 km per litre of fuel to DKK 18,460 for cars driving <4.5 km per litre of fuel. For diesel cars the rates vary from DKK 160 for cars driving at least 32.1 km per litre of fuel to DKK 25,060 for cars driving <5.1 km per litre of fuel.
FRANCE	**Regional tax** on registration certificates (the 'carte grise') is increased for cars emitting >200 gCO_2/km. The basic tax varies between €25 and €46 according to the region. Cars emitting >200 gCO_2/km pay an additional €2 for each gram between 200 and 250 gCO_2/km, and €4 for each gram >250 gCO_2/km. **Company car tax** is based on CO_2 emissions. Tax rates vary from €2 to €19 for each gram emitted depending on the car's total CO2 emissions: ≤ 100 gCO_2/km €2/g; >100 and ≤120 €4/g; > 120 and ≤140 €5/g; >140 and ≤160 €10/g; >160 and ≤200 €15/g; >200 and ≤250 €17/g; >250 €19/g.
GERMANY	In July 2009 the Federal Government introduced a system consisting of a **base tax** and a **CO_2 tax**. The rates of the base tax will be €2 per 100 cc (petrol) and €9.50 per 100 cc (diesel) respectively. The CO_2 tax will be linear at €2 per gCO_2/km. Cars with CO_2 emissions below 120 gCO_2/km will be exempt (below 110 gCO_2/km in 2012–13, below 95 gCO_2/km subsequently).
ITALY	A **tax incentive** of €800 and a two-year exemption from **circulation tax** is granted for the purchase of a new passenger car complying with the Euro 4 or Euro 5 exhaust emissions standards and emitting not >140 gCO_2/km, provided a Euro 0 or Euro 1 car is scrapped simultaneously. The exemption from circulation tax is extended to three years for cars with a cylinder capacity below 1,300 cc.

43 The new 'first-year' VED differentials introduced in 2010 may increase the impact of circulation tax to a degree.

Table 5.1: Selected CO_2-based vehicle taxes in the EU (as of 2009) cont.

EU STATE	METHOD OF CALCULATING ANNUAL CIRCULATION TAX
THE NETHERLANDS	The rate of the **registration tax** (based on price) is reduced or increased in accordance with the car's fuel efficiency relative to that of other cars of the same size (length x width). The maximum bonus is €1,000 for cars emitting under 20% less than the average car of their size; the maximum penalty is €540 for cars emitting over 30% more than the average car of their size. Hybrid cars benefit from a maximum bonus of €6,000.
PORTUGAL	**Registration tax** is based on engine capacity and CO_2 emissions. The CO_2 component is calculated as follows: petrol cars emitting <120 gCO_2/km pay €0.41/g; diesel cars emitting <100 gCO_2/km pay €1.02/g. The highest rates are for petrol cars emitting >210 g [(€29.31 x gCO_2/km) – 5,125.01] and for diesel cars emitting >180 g [(€34.20 x gCO_2/km) – 4,664.64]
SPAIN	A **registration tax** is based on CO_2 emissions. Rates vary from 0% (up to 120 gCO_2/km) to 14.75% (200 gCO_2/km and more). Purchasers of new cars emitting a maximum of 140 gCO_2/km and costing a maximum of €30,000 can obtain an **interest-free loan** up to €10,000 if they have a car that is ten years old or more (or that has a mileage exceeding 250,000 km) scrapped simultaneously.
SWEDEN	**Circulation tax** for cars meeting the Euro 4 exhaust emission standards is based on CO_2 emissions. The tax consists of a basic rate (360 Swedish krona, SEK) plus SEK 15 for each gram of CO_2 emitted above 100 gCO_2/km. For diesel cars, this sum is multiplied by 3.5. For alternative fuel vehicles, the tax is SEK 10 for every gram above 100 gCO_2/km.
UNITED KINGDOM*	**Circulation tax** is based on CO_2 emissions. Rates range from £0 (band A ≤100 gCO_2/km) to £405 for cars emitting >225 gCO_2/km. From 2010, new 'first-year' rates also apply which range from £0 (band A: ≤100 gCO_2/km) to £950 for cars emitting >225 gCO_2/km. **Company car tax** rates range from 10% of the car price for petrol cars emitting ≤120 gCO_2/km to 35% for cars emitting >235 gCO_2/km. Diesel cars pay a 3% surcharge.

*Updated to reflect 2010/11 tax figures.

Primary source: ACEA (2009) – original data amended and additional data added by Ecolane

Table 5.2: Selected tax incentives for BEVs in the EU (as of 2010)

EU STATE*	METHOD OF INCENTIVISING ELECTRIC VEHICLES
AUSTRIA	As part of a wider feebate scheme, alternative fuel vehicles including hybrid electric vehicles attract an additional **rebate** of up to €500 – valid until 31 August 2012. Electric vehicles are **exempt from fuel tax** and from the monthly vehicle tax.
BELGIUM	Purchasers of electric cars receive a personal **income tax reduction** of 30% of the purchase price (up to a maximum of €9,000).
DENMARK	Electric vehicles weighing less than 2,000 kg are **exempt from the registration tax**. This exemption does not apply to hybrid vehicles. The registration tax is based on the price of the vehicle. It is calculated as follows: (105% x vehicle price up to DKK 79,000) + (180% x vehicle price above DKK 79,000).

Table 5.2: Selected tax incentives for BEVs in the EU (as of 2010) cont.

EU STATE*	METHOD OF INCENTIVISING ELECTRIC VEHICLES
FRANCE	Using a **feebate system**, a premium is granted for the purchase of a new car when its CO_2 emissions are 125 gCO_2/km or less. The maximum premium is €5,000 for vehicles emitting 60 gCO_2/km or less. This incentive will remain in place until 2012. For such vehicles, the amount of the incentive cannot exceed 20% of the vehicle purchase price including VAT, increased by the cost of the battery if this is rented. Hybrid vehicles emitting 135 gCO_2/km or less receive an incentive of €2,000.
GERMANY	Electric vehicles are **exempt from the annual circulation tax** for a period of five years from the date of their first registration. Subsequently, they pay a tax amounting to €11.25 (up to 2,000 kg), €12.02 (up to 3,000 kg) or €12.78 (up to 3,500 kg) per 200 kg of weight or part thereof.
THE NETHERLANDS	Hybrid vehicles with an energy efficiency label A benefit from a maximum **reduction in registration tax** of €6,400. For hybrid vehicles with a B label, the maximum bonus is €3,200. The registration tax is based on price and CO_2 emissions.
PORTUGAL	Electric vehicles are totally **exempt from the registration tax**. Hybrid vehicles benefit from a 50% reduction of the registration tax. This registration tax is based on engine capacity and CO_2 emissions
SPAIN	Various regional governments **grant tax incentives** for the purchase of alternative fuel vehicles including electric and hybrid vehicles: Aragón, Asturias, Baleares, Madrid, Navarra, Valencia, Castilla la Mancha, Murcia and Castilla y León give €2,000 for hybrids, €6,000 for electric vehicles; Andalucía gives up to 70% of the investment.
SWEDEN	Hybrid vehicles with CO_2 emissions of 120 gCO_2/km or less and electric cars with an energy consumption of 37 kWh per 100 km or less are **exempt from the annual circulation tax** for a period of five years from the date of their first registration. For electric and hybrid vehicles, the taxable value of the car for the purposes of **company car taxation is reduced** by 40% compared with the corresponding (or a comparable) petrol or diesel car. The maximum reduction of the taxable value is SEK 16,000 per year.
UNITED KINGDOM	Electric vehicles are **exempt from the annual circulation tax**. This tax is based on CO_2 emissions, and all vehicles with emissions below 100 gCO_2/km are exempt from it. As from 1 April 2010, electric cars receive a five-year **exemption from company car tax**, and electric vans a five-year exemption from the van benefit charge (£3,000). As from 2011, purchasers of electric vehicles (including plug-in hybrids) will receive a **Plug-in Car Grant** equivalent to 25% of the vehicle's list price up to a maximum of £5,000. The government has set aside £230m for this incentive programme.

*Incentives for electric vehicles are currently applied in all western European countries except of Italy and Luxembourg.

Source: ACEA (2010)

It was factors beyond the control of government, namely the fuel price peaks of 2008 and the subsequent recession, that accelerated the reduction of CO_2 emissions within the conventional UK new car market. As already discussed in Section 3.2, these events resulted in a sudden downsizing in new cars, with the 'biggest drop in new car CO_2 on record' – falling 3.6% in the second quarter of 2008 and then 5.5% in 2009 (SMMT, 2008; Next Green Car, 2009a). The cumulative impact has been to rescale the level of annual CO_2 reductions for new cars – figures from the Society of Motor Manufacturers and Traders (SMMT) show that new car CO_2 fell 4.7% in first half of 2010 compared with 2009, to 145 g CO_2/km (Next Green Car, 2010b).

As noted in the previous section, only London's AFD, with a value of at least £2,000 per year, has been a significant driver of lower emission vehicles. Sales of hybrids (such as the Toyota Prius) have been particularly high in the region – whereas (in 2007) 12.5% of Toyota UK sales were in VED band B, 34% of the company's London sales were in band B (AEA Energy & Environment, 2007). The AFD is also the reason that the majority (60%) of the UK's fleet of electric vehicles are operated within the capital (Girard, 2010).

The evidence suggests, therefore, that conventional rates of circulation tax are unable to incentivise lower and ultra-low carbon vehicles. While very high circulation tax cost differentials could be used to stimulate adoption of ULCVs, it is unlikely that these would be politically acceptable. Instead, this report concludes that an alternative type of incentive is necessary, one that more closely matches the attitudinal responses of consumers. Given that vehicle price is one of the most important consumer factors during car purchase (see Section 3.2), introducing financial incentives at the point of purchase or registration would seem to offer the most effective leverage in promoting the uptake of ULCVs.

To assess this proposition, this review first notes historical analysis of European data conducted by Wallis (2005). Comparing the level of registration taxes and fuel economy improvement (for conventional cars) over the period 1970 to 1998 for five European countries, Wallis (ibid.: 712) concludes that 'European countries that have adopted purchase tax regimes favouring smaller cars also have more fuel-efficient national fleets'. Indeed, the wider literature suggests that one particular type of purchase incentive scheme can be particularly effective in influencing car buying decisions. These are purchase 'feebates', which combine an integrated system of registration fees for the most polluting vehicles with purchase rebates for cars with the lowest emissions.

The effectiveness of purchase incentives is well illustrated by the evaluation of the one-year scheme in the Netherlands. This found that, compared to 2001, the market share of band A cars in 2002 increased from 0.3% to 3.2%, while that of band B cars rose from 9.5% to 16.1% (Gärtner, 2005). The removal of the incentive in 2003 (due to budgetary constraints) resulted in a drop in market share for band A and B vehicles, but their combined total still remained 27% higher than in the pre-incentive year. The report by ADAC (Allgemeiner Deutscher Automobil Club, Germany's and Europe's largest automobile club) concluded that '[registration] tax incentives… are well accepted by consumers and seem to have a great impact on vehicle purchase decisions'.

Compelling evidence in support of feebates is also presented by the International Council on Clean Transportation (ICCT) as part of a comprehensive review of feebate schemes worldwide (German & Meszler, 2010). Assessing the effectiveness of a new French feebate system introduced in 2008,[44] the ICCT reports that average CO_2 emissions of the new car fleet fell by 9 gCO_2/km, or approximately 6%, in one year – almost twice the average CO_2 emission reduction of 3.1% in the EU during the same period, and significantly higher than the average annual reduction of 1.2% in France from 2000 to 2007. Controlling for other factors influencing the French car market, the ICCT report concludes that this market shift is attributable to the new feebate system.[45]

In another paper which assesses the potential effectiveness of feebates, de Haan et al. (2009) use an agent-based micro simulation model to predict environmental and market effects of feebates on the Swiss new car market. Modelling the impact of a €2,000 rebate for A-labelled cars (with an equivalent fee for cars with the poorest fuel economy), they predict an additional reduction in new car CO_2 emissions of 4.3% within the first 12 months of implementation.

44 The French scheme offers rebates of €5,000 for <=60 gCO_2/km, €1,000 for <=95 gCO_2/km, €500 for <=115 gCO_2/km, €100 for <=125 gCO_2/km; has a zero-rating for 126–155 gCO_2/km; and charges fees of €200 for <=160 gCO_2/km, €750 for <=195 gCO_2/km, €1,600 for <=245 gCO_2/km and €2,600 for >245 gCO_2/km.

45 The ICCT notes that car sales in 2008 were virtually unaffected by the economic downturn (decreasing by only 0.7% from 2007 to 2008), while a bonus program for scrapping old vehicles did not start until December 2008. While fuel prices were at a peak in 2008, this was the case for all countries within the EU.

The research also finds that, for this simulation, consumers continue to choose vehicles within the same segment, but opt for more efficient engines with lower emissions. Although the model focuses on the Swiss market, the authors contend that the findings are applicable to all European car markets.

Evidence from the US also finds that 'up-front' incentives have had a significant impact on adoption rates of HEVs. In a cross-sectional analysis of HEV registrations from 2001 to 2006, Diamond (2009) concludes that sales or excise tax waivers (which reduce the price at point of purchase) have had a more noticeable impact on HEV registrations than tax credits (which take longer for the consumer to receive). Similar findings are reported by Gallagher and Muehlegger (2008).

In support of feebate schemes, German and Meszler (2010), the authors of the ICCT report, provide three key reasons for the apparent success of feebates. First, they note that consumers tend to be 'loss averse', tending to reject products were the benefits are unknown. Second, consumers find future fuel cost reductions difficult to quantify for a number of reasons, including variation in driving style and fluctuations in fuel price. And third, as feebates provide clear pricing for CO_2 abatement technologies, manufacturers are more able to assess the costs of bringing new technologies to the market, and plan their innovation strategy accordingly.

Based on their global review, the ICCT also provides best practice for feebate policy design and recommend the following: fees and rebates should scale continuously and linearly with CO_2 emissions or a measure of fuel consumption; the 'pivot point' should be set to make the system self-funding and sustainable, and periodically adjusted to compensate for improving emissions performance; and an attribute adjustment (if one is used) should be based on vehicle size. Furthermore, the revenues from fees should be used solely to fund rebates, creating a revenue-neutral incentive programme. While not a recommendation, German and Meszler observe that most successful feebate schemes have incentive gradients of €18–€30 (£15–£25) per gCO_2/km for the range of emissions over which the feebates apply.

Researchers also make three interesting attitudinal observations about feebates. First, assessing data from a large-scale consumer survey, Peters et al. (2008) note that feebates yield acceptance rates equal to those for purely informational measures – rates which are already known to be high. Second, in a related paper, Coad et al. (2009) propose that that the information part of feebates (i.e. the Fuel Economy Label) may be effective in encouraging 'intrinsically' environmentally motivated consumers to adopt lower emission cars, while the financial part may be more persuasive for 'extrinsically' motivated, less environmentally oriented, consumers. And third, Lyons et al. (2004) observe that the public generally prefer revenue-neutral policies to revenue-generating systems of taxation.

5.2 Improving consumer information

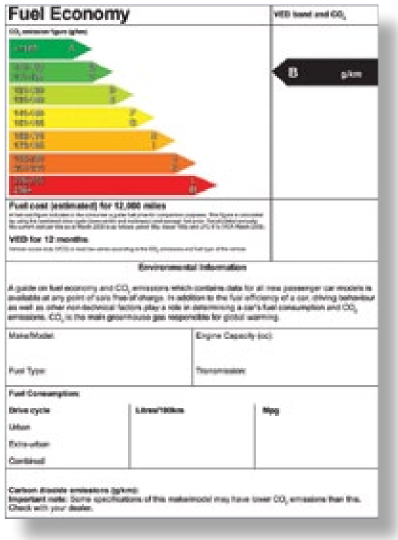
As highlighted by a major review of public attitudes to climate change and transport behaviour conducted for the Department for Transport, information provision is necessary, but rarely sufficient to encourage pro-environmental behaviours (including the purchasing of low emission cars) (Anable et al., 2006). As cited in the review, Collins et al. (2003) conclude that, for a policy to be successful, providing information needs to be accompanied by other measures implemented in parallel, including the development of the required infrastructure to enable change; effective incentives and disincentives (i.e. economic instruments); and a level of user-acceptance of the policy measure in question.

Demos and the Green Alliance reinforce this point, stating that: 'Information does not necessarily lead to increased awareness, and increased awareness does not necessarily lead to action. Information provision, whether through advertisements, leaflets or labelling, must be backed up by other approaches' (quoted in Anable et al., 2006: 138–39).

Despite the considerable weight of evidence supporting this position, until relatively recently, the 'deficit model'[46] continued to be the default position of some campaigns aimed at changing behaviour – one example being the 'Are You Doing Your Bit?' campaign launched in 1998. The limitation of this approach is that it persists in viewing the consumer as a 'rational actor', and fails to account for the complex range of motivations underlying actual behaviour. As was discussed in Section 3.2, one example relevant to this review is the apparent contradiction between consumers' engagement in 'green' issues and the low priority given to environmental factors at the point of car purchase.

That said, the academic literature on promoting pro-environmental behaviour also maintains that, without the provision of relevant and authoritative information, consumers are not able to engage with policy, and are less likely to be aware of the opportunities to act. A useful distinction is also made between 'abstract' knowledge of the issues and 'procedural' knowledge which focuses on action strategies. Whilst abstract knowledge can be used to 'sensitise' consumers to the issues, information on what to do and how to do it is more important in effecting change.

46 The deficit model assumes that if only people knew and understood more about connections between their own behaviour and a range of environmental threats, they would act in a more sustainable way.



Of key relevance to the purchase of ULCVs is the information provided by the Fuel Economy Label, introduced in 2001 as a result of the EU Directive 1999/94/EC, which requires comprehensive labelling for all new cars providing information on CO_2 emissions and fuel economy. Updated in 2005, the UK label presents graduated VED information using colour coded bands (originally developed for consumer 'white goods'), and also provides information about CO_2 emissions, average fuel economy, and annual fuel and VED costs.

For conventional cars at least, a recent GfK Automotive survey found that around half (49%) of new car buyers recall having seen the label when purchasing their current car, with 59% recognising the label on being presented with an example (Dixon & Hill, 2009). The survey also concludes that nearly three quarters (71%) of new car buyers *report* finding the information useful in selecting a model.[47]

However, a more qualitative focus group study conducted for LowCVP casts doubt on the actual impact of the label on vehicle choice (Lane & Banks, 2010). When pressed on whether environmental information had been accessed during the search process, it was clear that for most participants such information was either not used or not well understood. In particular, only a few recent car purchasers were able to recall seeing the Fuel Economy Label in the showroom, and there was little evidence that the label had been actively used to make comparisons. As has already been discussed (see Section 3.2), the survey again concludes that for most car buyers, environmental information is not an important factor for car selection and that the information is not presented in an engaging way.

The LowCVP survey goes on to explore which elements of the current label are most effective in conveying environmental information to car buyers. On a positive note, almost without exception, consumers respond very positively to the colour banded A–M format – many participants note its familiarity, while others recognise its equivalent on 'white goods' consumables. It can be concluded that the format has achieved an almost 'brand' status, and the design is an important visual cue that environmental information is being presented.

However, following detailed discussions with car buyers, the survey recommends that the current label would be improved by changing its format and content. These recommendations include: presenting fuel economy information (in terms

47 It should be noted that there is an important distinction between factors that consumers report as influencing their purchasing behaviour and factors which actually modify behaviour (as externally observed).

of ‘mpg’) alongside CO_2 emissions; increasing the text size of key information metrics, and adding in comparative ‘best-in-class’ information.[48]

Of particular relevance to the emerging ULCV markets is the provision of life cycle (or ‘well-to-wheel’) emissions information. The LowCVP report recommends that, for a future EU fuel economy label, further research into the most effective life cycle metrics and formats should be considered, particularly to take into account the life cycle implications of new technologies such as BEVs and PHEVs. This is based on the survey’s findings that a significant (and growing) minority do appear to be interested in life cycle information, with the caveat that it should be simply presented.[49]

As noted by the King Review, while upstream processes (associated with fuel production and vehicle manufacturing) currently account for around 15% of greenhouse gas emissions, this proportion will rise over time as fuel economy improves. For ULCVs, for which most or all of the emissions are produced away from the vehicle, some level of consumer appreciation of life cycle emissions is paramount. As King states, future information provision needs to ensure that ‘the emissions and the broader environmental impact of production and disposal are not ignored and that the sustainability of new methods is captured’. The report also calls for the ‘New European Drive Cycle’, which generates the official CO_2 emissions and ‘combined’ fuel economy data for all cars sold in the EU, to be reviewed as regards its ability to reflect actual environmental impact of existing and future vehicle types.

One further issue is the provision of web-based information. Given that the Internet is the now most important source of information for car buyers (Lane & Banks, 2010), it perhaps surprising that there is no official UK Government website which specifically focuses on ULCVs. This contrasts with the situation in the US, where the Environmental Protection Agency, which performs many of the functions of the UK’s Vehicle Certification Agency, provides environmental information for consumers. In the UK, this service is currently provided by private sector websites including WhatGreenCar, Clean Green Cars, and Green Car Guide.

While the ActOnCO_2 campaign (launched in 2007) does focus on lower emission conventional models, there is some evidence that relatively few consumers are aware of the online database provided by the programme. The LowCVP survey already cited also found that, while most participants were positive about the ActOnCO_2 website (when it was presented to them), many noted the omission of key information on the results page – namely fuel economy (‘mpg’) and vehicle price – and implied that they would have found the site of more use had this information been present.

48 Choosing the ‘best in class’ vehicle in the current market would reduce tailpipe CO2 emissions by an average of 25% (HM Treasury, 2007).

49 The LowCVP report identifies the specific issues of consumer concern as: the environmental impact (and locality) of production, materials recyclability, and the transport of products from the point of production to the consumer.

5.3 Supporting future innovation

Despite the fact that consumer incentives have not been radical in their design or implementation to date, it is true that UK Governments (past and present) have done a great deal in supporting innovation of low carbon and ultra-low carbon vehicle technologies.

Supported by several government departments, the Research Councils and the automotive industry, an interconnected set of organisations already implement a strategic innovation strategy aimed at developing the ULCV sector (HM Treasury, 2008). Notable players include the Technology Strategy Board (TSB), funded by the Department for Business, Innovation and Skills, which supports collaborative R&D through Knowledge Transfer Networks, the Low Carbon Vehicles Innovation Platform and Cenex.

Other agencies managing the innovation process are the Energy Technologies Institute (a UK-based private company formed from, and funded by, global industries and the UK Government) and the Environmental Transportation Fund, the Energy Saving Trust and the Carbon Trust, all of which are partly or wholly funded by the Department for Environment, Food and Rural Affairs, the Department for Energy and Climate Change, and/or the Department for Transport. The academic Research Councils also provide support to the UK Energy Research Centre, which has a strong transport focus.

Following the King Review in 2008, the Government also launched the New Automotive Innovation and Growth Team (NAIGT), an industry-led steering group that has developed a 20-year strategy for the UK automotive industry – and the Automotive Council, set up to facilitate industry R&D and implementation to bring the strategy to fruition. King also recommended that the TSB should provide further demonstration opportunities through fleet trials linked to future procurement opportunities, both of which have been implemented in the intervening period.

Although uncertainty remains about precisely which technological pathway will best accelerate the decarbonisation of road transport, there is a consensus that electrification of the vehicle drive-train is almost inevitable. Given that many parts of the UK industry already working towards this end, and considering the positive results of the TSB-funded Ultra-Low Carbon Vehicle Demonstrator projects (as discussed in Section 3.4), the evidence suggests that the existing innovation programmes are both well timed and successfully contributing to a realignment of the UK automotive industry.

As noted by Arup and Cenex (2008) and the King Review (HM Treasury, 2007; 2008), the UK's automotive sector has a global reputation for research and development, design engineering and manufacturing.[50] The future development

50 The UK automotive manufacturing sector makes a significant contribution to the UK economy. It employs around 210,000 people, contributes over £9 billion per year, and represents 6.2% of manufacturing value-add and 11% of UK exports. UK production includes over 3 million engines per year, representing over 25% of European production.

of ULCVs therefore provides an important opportunity for the UK to take a lead in the development and deployment of new vehicle technologies (Arup & Cenex, 2008). In particular, the UK automotive sector is in a good position to capitalise on its skill base in R&D, innovation and the licensing of low carbon technologies.

In parallel with technological development, the last decade has also seen the emergence in the UK of a ‘mobility service’ sector which offers new methods of vehicle procurement, and has particular synergy with new vehicle technologies. ‘Car clubs’, for example, have the potential to accelerate the adoption of ULCVs, changing as they do the payment structure of car ‘ownership’ (Cairns, 2011). Based on a ‘pay-as-you-drive’ business model, car clubs are able to offer ULCVs to customers using price tariffs that circumvent the capital cost barrier usually associated with new technologies. Indeed, BEVs are already available from at least one car club station in London.[51]

51 London Borough of Camden. *Private communication.*

Two other reasons also make car clubs ideally suited for promoting ULCVs. First, through the national network of over 2,200 cars, the four main UK clubs have already established a membership base of over 100,000 users. This network, with its associated booking infrastructure, could be used to offer test drives of ULCVs to club members to widen the experience base, which – the evidence suggests – is important in catalysing the emerging market (see Section 3.4). Furthermore, there is the observation that early adopters of ULCVs have much in common with those drivers most likely to join a car club (Cairns, 2011).

Other mobility services that combine elements of both conventional leasing and car sharing schemes are being developed by the more established car hire sector. One such scheme, 'Mu', which has been launched in the UK by Peugeot at selected dealerships, offers members extended rental of vehicles and car accessories. In 2011, the scheme will be used to launch the Peugeot iOn BEV, which will only be available to lease as part of the Mu service. It remains to be seen, however, if these types of scheme are commercially viable in the long term.

This section concludes with the observation that, while much has been accomplished to support technological and mobility service innovation within the automotive sector, the consumer has only recently become the central focus of the publicly funded ULCV innovation process – primarily through the TSB-supported trials (see Section 3.4). The success of the real-world trials in raising expectations among consumers demonstrates the importance of giving potential users 'hands-on' experience of new vehicle technologies – many of which offer a new driving experience as well as fewer emissions.

The importance of users in the innovation process has long been established within Innovation Theory. The seminal research by Rogers (1971) points to the importance of users (organisational and/or individuals) within the diffusion process. Rather than merely acting as passive recipients of new products or services, the perceptions, beliefs and behaviour of users strongly determine the success or otherwise of an innovation. Indeed, if surveyed at an early stage, user feedback can be used as an invaluable tool to facilitate the diffusion process.

As noted by Lane in 2000: 'If AFVs [alternatively fuelled vehicles] are to succeed in the wider marketplace, promoters will need to have at least a rudimentary idea of how these new technologies will be received. Policy makers too, will be greatly assisted in their efforts to introduce AFVs if the current level of general knowledge and understanding of the technologies employed is fully appreciated.'

This review therefore recommends further incorporating potential ULCV users in the innovation process in order to promote organisational or 'second-order' learning[52] as adopted by innovation strategies such as Constructive

52 In single-order learning, individuals or organisations modify their actions according to the difference between expected and obtained outcomes. In second-order learning, the participants question the values, assumptions and policies that led to the actions in the first place. If they are able to view and modify those, then second-order learning has taken place.

Technology Assessment, which advocates widening the discussion to include more partners than are usually considered as part of the design process (Schot & Rip, 1997), and Strategic Niche Management, which endeavours to support new innovations through smart experimentation (Hoogma et al., 2002). In summary, there is a need to fully include consumers within the innovation process to facilitate 'collaborative disruption' of the existing regime, dominated as it is by the ICE, to a future regime which is defined by the electric drive-train.

As part of this inclusive strategy, there may be a need for a greater 'consumer voice' within the innovation network already established. To this end, the King Review recommended that the then new Research Centre on Sustainable Behaviours should take on this role by making low carbon cars a priority research field. There may be further opportunities for increasing the consumer voice within the innovation process by establishing a new consumer organisation or forum within the networks already discussed in this section. Possible names and positions for this new body include: the 'Consumer Working Group', managed by the Low Carbon Vehicle Partnership, and the 'Car Consumer KTN', located within the existing Knowledge Transfer Network.

6. Summary and Recommendations

The evidence reviewed suggests that the ULCV market is at a critical phase. While it is the case that ULCVs (particularly BEVs) have received significant global interest and investment for several decades, only now has the technology evolved to a stage where the mass commercialisation of electric vehicles can be realistically contemplated.

Furthermore, production costs, government policy and consumer attitudes have also synergistically developed in such a way as to increase the chances of successful market penetration by ULCVs. With several well-branded high-quality models being prepared for launch, 2011 and 2012 are likely to be crucial years which could mark the shift from vehicle development to commercialisation.

The potential benefits of mass adoption of ULCVs are significant – using current technologies, per-mile greenhouse gas reductions are in the region of 30–50%, with the potential for long-term reductions of 50–80%. The implication is that, in conjunction with the decarbonisation of the electricity sector and behavioural change, ULCVs can help deliver the 90% reduction in vehicle emissions per mile identified by the King Review.

However, no matter how ready the technology may be, consumer willingness to adopt ULCVs will be central to initiating the market shift away from conventional technologies, and will ultimately determine the long-term market penetration rates.

Although consumers are concerned about climate change, the evidence shows that this concern will not be sufficient on its own to stimulate demand. To reach the mass market, the average car buyer will also need to be convinced that the ULCV models on offer are affordable, reliable and – most importantly – desirable.

With the consumer foremost in mind, and based on the evidence presented in previous sections, this review concludes by making ten recommendations to the RAC Foundation regarding possible issues that merit further exploration – issues which could form the focus for future Foundation-funded research.

6.1 Recommendations for further research

The recommendations made here concern primarily the role of the consumer in the market development of ULCVs in the UK. For clarity, the recommendations are grouped in to four key areas:

- informing the consumer;
- understanding the consumer;
- incentivising the consumer; and
- improving policy and innovation.

Informing the consumer

The review shows that the current level of public awareness and knowledge of ULCVs is relatively low, particularly in the case of PHEVs and FCVs. Even regarding BEVs, the most commonly known type of ULCV, the average consumer has little detailed knowledge about their operation, driving experience or potential benefits. Research also suggests that the consumer preconceptions about ULCVs risk becoming fixed unless communication is improved.

While the review provides evidence that information alone is not sufficient to markedly influence consumer behaviour, it also makes it clear that, where levels of knowledge are low, providing information is necessary as part of a wider promotion strategy. In particular, having access to 'procedural' knowledge – information on what to do and how to do it – is important in effecting change. Despite the need for more consumer information, the review notes that, currently, there is no official UK Government source of information which specifically focuses on ULCVs.

One of the strongest findings from the evidence presented is that providing opportunities for consumers to get 'hands-on' experience of ULCVs is very effective in raising expectations. Following real-world trials of BEVs, consumer acceptance is found to increase, suggesting that, in general, ULCVs perform better than consumers expect. Most encouragingly, consumers in the 20–30 year age group, and those with no prior experience, exhibited the largest positive shift in attitudes towards electric vehicles.

With regard to consumer information, this evidence review therefore makes the following two recommendations:

***Recommendation 1** – Research should be conducted to assess the future requirements for UK consumer-focused information regarding ULCVs, with particular focus on web-based sources.*

***Recommendation 2** – Research should be conducted to assess the feasibility of providing consumers with the opportunity to test-drive ULCVs, either using existing networks or through a national network of test-drive centres.*

Understanding the consumer

While fuel production and vehicle manufacturing emissions currently account for around 15% of greenhouse gas emissions for conventional vehicles, for ULCVs most or all of the emissions are produced away from the vehicle. As noted by the King Review (HM Treasury, 2008: 38), future information provision therefore needs to ensure that 'the emissions and the broader environmental impact of production and disposal are not ignored and that the sustainability of new methods is captured'.

In addition to noting the industry's need to improve the measurement of environmental impact for new vehicle types, the review reports that a growing minority of consumers appear to be interested in life cycle information, with particular focus on the locality of production, materials recyclability, and the transport from the point of production to the point of sale. Research is therefore required to assess the most effective and understandable metrics that are able to convey the life cycle implications of new technologies such as plug-in hybrid and battery electric vehicles.

As noted in the review, the literature also highlights an important aspect of car ownership, one that is often omitted from assessments of consumers' attitudes towards ULCVs. This is the symbolism attributed to particular makes, models or vehicle types – through ownership, car buyers communicate to others who they are: their interests, beliefs, values, and social status. Any car can have symbolic value, but the evidence suggests that symbolism is particularly strong for vehicles that use new types of technology. Understanding how ULCVs are valued by consumers will, therefore, provide important insights into the most effective promotional and marketing strategies.

With regard to understanding the consumer, this evidence review therefore makes the following two recommendations:

***Recommendation 3* – Research should be conducted to assess the most effective methods of conveying life cycle information to UK consumers, particularly to take into account the life cycle implications of ULCVs.**

***Recommendation 4* – Research should be conducted to understand the extent and importance of symbolism attributed to ULCVs in the UK.**

Incentivising the consumer

With the current price premiums on ULCVs – from at least 30% for a PHEV with a 20-mile electric range, to (until recently) at least 100% for a BEV – the purchase price of most ULCVs remains a key barrier to their adoption by the mass market. Given that the willingness-to-pay for new vehicle technologies tends, for early adopters, to be limited to a premium of around 15% on the price, and is less for later-adopting market segments, financial incentives are therefore likely to be needed in order to stimulate mass consumer demand.

The review observes that the current incentives offered through circulation taxes are not sufficient in themselves to promote a significant switch to new vehicle technologies. Instead, the review provides compelling evidence in support of incentives applied at the point of purchase – the rationale being that purchase price is one of the most important factors influencing vehicle choice. In particular, the review highlights the success of 'feebates', which combine an integrated system of registration fees for the most polluting vehicles with rebates for cars with the lowest emissions.

In support of feebates, the review notes the effectiveness of the French feebate system introduced in 2008, in which the average CO_2 emissions of the new car fleet fell by around 6% in one year – almost twice the average CO_2 emission reduction in the EU during the same period, and significantly higher than the average annual reduction of 1.2% in France from 2000 to 2007.

While the new Plug-in Car Grant – which provides up to £5,000 towards the cost of a new BEV or PHEV – will be available in the UK from January 2011, the funding is limited to £43 million.[53] Although a significant amount, this will only

53 Whereas the original announcement has earmarked £230 million for the consumer grants, the Coalition has only committed £43 million for the scheme up to March 2012 – a potential budget cut of 80%. The scheme will be reviewed in January 2012.

be able to support around 8,600 applicants in the first tranche. If capital grants are needed over the longer term to stimulate demand, a self-financing system – such as a 'feebate' scheme – will be required. The review notes that, to date, few in-depth studies have designed such a scheme for the UK, or assessed its likely effectiveness.

Regarding the provision of a recharging infrastructure for BEVs, the review notes that around 80% of UK car-owning households already have access to a garage or other off-street parking facility, and points out that some assessments conclude that the existence of a publicly accessible network of 'slow' recharging points would have limited additional benefit for the adoption of BEVs. The implication is that the existing electricity supply accessed through standard home-based (13A) sockets will be sufficient to provide recharging facilities for a significant switch to electric vehicles.

Given the obvious importance of home charging to the emerging BEV market, it is worth noting that, currently, there is little or no financial or informational home-charging support for consumers contemplating owning a BEV. Considering the significant investment being made to expand the public-access recharging network, this review suggests that BEV adoption might be more effectively supported (and at a lower cost) by supporting consumers wanting to recharge BEVs at home.

With regard to incentivising the consumer, this evidence review therefore makes the following two recommendations:

***Recommendation 5* – Research should be conducted to design and assess the likely effectiveness of a technology-neutral UK purchase 'feebate' scheme for ULCVs.**

***Recommendation 6* – Research should be conducted to explore low-cost methods of supporting UK consumers who want to charge ULCVs at home.**

Improving policy and innovation

Although the review highlights the benefits of supporting home-based EV charging, it also acknowledges that on-street charging may be necessary from an attitudinal perspective to encourage BEV and PHEV adoption. The central questions here are: on what scale are public access recharging locations really required (in terms of their level of utilisation), and to what extent should resources be focused on supplying them in sufficient numbers to provide psychological reassurance?

Regarding consumer-focused policies intended to support ULCV adoption, one general issue arising during the review is the need to further harmonise local and regional measures – there is at least some anecdotal evidence of the confusion caused, for example, by the range of parking and charging incentives used by different London boroughs to promote use of BEVs.

Regarding a specific policy, the review highlights the King Review's recommendation that the 'New European Drive Cycle', which generates the official CO_2 emissions and 'combined' fuel economy data for all cars sold in the EU, should be reviewed as regards its ability to reflect actual environmental impact of existing and future vehicle types. This issue is particularly pertinent for ULCVs, as the refuelling cycles used in test conditions have yet to be standardised – and also relates to the need to provide concise and easy-to-understand life cycle information to consumers (see Recommendation 3).

Drawing on the positive outcomes of the real-world trials, this review highlights the benefits of involving potential ULCV users in the innovation process in order to promote organisational or 'second-order' learning – as adopted by innovation strategies such as Strategic Niche Management, which endeavours to support new innovations through 'smart' experimentation.

To achieve a more inclusive innovation strategy, the review identifies the need for a greater 'consumer voice' within the innovation networks already established, and proposes the establishing of a new organisation or forum to represent the ULCV consumer. Possible names and positions for this body include: the 'Consumer Working Group', managed by the Low Carbon Vehicle Partnership, and the 'Car Consumer KTN', located within the existing Knowledge Transfer Network.

With regard to improving policy and innovation, this evidence review therefore makes the following four recommendations:

***Recommendation 7** – Research should be conducted to assess what scale of UK public access recharging locations is required for adoption of electric vehicles, and to what extent resources should be provided if their primary purpose is to provide psychological reassurance to the consumer.*

***Recommendation 8** – Research should be conducted to compare local and regional UK policies supporting ULCVs, with a view to assessing the potential for further integration and standardisation across the UK.*

***Recommendation 9** – Research should be conducted to assess the suitability of the current 'New European Drive Cycle' (the current industry-standard test cycle used for calculating fuel consumption figures) for reflecting the full emissions impact of existing low carbon and future ultra-low carbon vehicles;*

***Recommendation 10** – Consideration should be given to the establishing of a new organisation or forum dedicated to understanding and representing potential purchasers and owners of ULCVs.*

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