BERR | Department for Business Enterprise & Regulatory Reform

Department for Transport

Investigation into the Scope for the Transport Sector to Switch to Electric Vehicles and Plug-in Hybrid Vehicles

October 2008

cenex

ARUP

Department for Business Enterprise and Regulatory Reform: Department for Transport

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Executive Summary

This study, jointly undertaken by Arup and Cenex on behalf of the Department for Business Enterprise and Regulatory Reform (BERR) and the Department for Transport (DfT), has investigated the scope for the transport sector to switch to vehicles powered through electricity from the grid in the period until 2030.

Road based transport currently accounts for approximately 22 per cent of the UK CO_2 emissions and therefore reducing the reliance on carbon based fuels in this sector is seen as a priority. As highlighted in the King Review of Low-Carbon Cars, road based CO_2 emissions reductions will come from a number of different sources including the development of alternative fuels such as hydrogen, continuing improvements in internal combustion engine efficiency and the wider rollout of hybrid powertrains, and lightweighting of vehicles.

The report was commissioned to provide a better understanding of the contribution that the introduction of battery electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) can make to the long-term reduction of the UK's CO_2 emissions.

This study has examined a number of factors which will influence the development, uptake and impact of EVs and PHEVs within the UK.

In particular the following have been considered:

- Possible scenarios for the uptake of these vehicles
- Comparison of the life cycle emissions and environmental impacts of these vehicles with petrol/diesel vehicles
- Battery technologies for EVs
- The impact of these vehicles upon the UK electricity grid
- Opportunities to develop UK business in support of vehicle development
- Barriers to be overcome and incentives required to help stimulate the market
- Demonstration projects to test and further understand the issues surrounding the mass introduction of these vehicles.

The study has focused primarily on cars and light goods vehicles as these are the most suitable for the application of EV and PHEV technologies and make up the greatest proportion of UK registered vehicles. The uptake of EVs in the medium term will be centred on urban environments and will start with city markets and van fleets. PHEVs with their increased flexibility will have greater penetration of the market in the medium term.

Key Findings

A number of key findings of the study are presented below. A full presentation of findings is given in section 10.

- EVs have the potential to offer significant carbon dioxide and greenhouse gas emissions reductions compared to conventional petrol/diesel fuelled internal combustion engines. This applies over a full life cycle, taking account of emissions from power generation and emissions relating to production and disposal. Based on the current UK grid mix there are already significant benefits of the order of approximately 40% reduction; these benefits have the potential to become much greater with further decarbonisation of the UK power mix.
- The impact of EVs and PHEVs on the UK electricity grid has been examined and there is sufficient generating capacity to cope with the uptake assuming that demand for

charging is managed and targeted at off-peak periods where there is currently surplus capacity. This could be achieved through variable electricity tariffs related to grid demand.

- The existing national transmission network will be sufficient to cope with the demand from vehicles. There may possibly be distribution issues where local networks are already close to capacity. In such circumstances this can be overcome with local reinforcement. The impact of vehicle charging on local networks and infrastructure is a critical area for study in future pilot and demonstration projects.
- The UK's automotive sector has a global reputation for research and development, design engineering and manufacturing. The development of EV and PHEV technology provides an opportunity for the UK to take a lead in the development and deployment of the new technologies required.
- A number of volume manufacturers have recently announced intentions to develop EVs and PHEVs. These will initially be introduced in to the UK market as demonstrators or in very low volumes. Due to vehicle development lead times, mass production and volume availability of EVs and PHEVs is unlikely to occur before 2014 at the earliest. Therefore up to this date the market will be supply constrained and uptake will be with early adopters.
- The wide spread roll-out and uptake of EVs and PHEVs after 2014 would require increased consumer confidence and education; improvements in battery performance and cost; charging infrastructure which keeps pace with demand; and stimulation of the market through appropriate incentives which encourage the uptake of low carbon vehicles. Without these a 'Business as Usual' scenario would prevail.
- Largely due to the high cost of batteries, the consensus is that EVs and PHEVs will cost more to produce than comparable existing vehicles for the foreseeable future. Over the medium term the whole-life running costs of EVs and PHEVs are expected to be lower than conventionally-fuelled alternatives, primarily due to differences in fuel prices. Currently private consumers buy on capital cost rather than running costs and so education will be required to raise awareness of this benefit.
- Pilot and demonstration projects will be critical to address the questions and concerns of all stakeholders involved in PHEV and EV in order to provide an evidence base for a possible future wider rollout of vehicles

Recommendations

- Create a forum for the development of the UK's EV industry and market. This could either be physical or virtual, but would need to bring together the many stakeholders involved including policy makers, vehicle manufacturers, electricity generators and distributors, technology specialists, research establishments, urban designers, transport planners etc. This would be a major step towards providing consistent and coherent industry direction to facilitate roll out. The exact aims and scope of this forum should be the subject of further work to ensure that it is able to provide maximum benefit.
- The UK should build on the favourable domestic environment created by work such as the King Review of Low-Carbon Cars to take a leading role in efforts to promote the creation of robust international standards and the sharing of international learning and experience as an essential prerequisite to the wider rollout of EVs.
- Set clear legislative landscape for 2020 and beyond with regard to vehicle efficiency standards, which will act as a driver for technological innovation. This will need to be undertaken as part of the European Union.
- Develop a 20 year roadmap for the ongoing development of EVs and PHEVs.
- Further develop relationships with existing UK manufacturers and also attract new manufacturers and high value engineering to the UK as a healthy manufacturing base draws in suppliers, expertise and funds for R&D. This must be structured to complement the existing automotive industry.
- Focus research on batteries, internal combustion engines for hybrids, electric motors, control systems, energy scavenging systems and battery recycling and ensure that this does not damage other areas of UK expertise and ongoing development such as powertrain.
- Under take further investigation to fully understand the range of potential environmental issues associated with lithium-ion batteries and methods of mitigation.
- Facilitate pilot and demonstration studies to be carried out which will enable further real-world research to be undertaken and to build market awareness and acceptance of EVs. These studies should grow in size to test scale and capability.
- Seek to ensure the deployment of charging infrastructure for EVs and PHEVs remains ahead of vehicle uptake. A shortage of charging points would reduce consumer uptake.
- EVs have the capacity to act as a distributed energy storage system although there are currently issues related to access and utilisation. Further work is recommended to understand in more detail the technical challenges, business case and overall viability of such a proposition.
- Consider facilitating the introduction of complementary policy measures that drive local market development and encourages the uptake of EVs and PHEVs.
- Educate the public on whole life vehicle operating costs, enabling EVs and PHEVs to compete with internal combustion engine vehicles in a balanced fashion.
- Raise public awareness about journey profiles to help them make informed choices on vehicle requirements and selection.

1 Introduction

Road based transport currently accounts for approximately 22 per cent of the UK CO_2 emission and therefore reducing the reliance on carbon based fuels in this sector is seen as a priority. Arup and Cenex, on behalf of the Department for Business Enterprise and Regulatory Reform (BERR) and the Department for Transport (DfT), have investigated the scope for the transport sector to switch to vehicles powered through electricity from the grid in the period to 2030.

This study was commissioned to provide a better understanding of the contribution that battery electric vehicles (EVs)[1] and plug-in hybrid electric vehicles (PHEVs) can make to this target and the long-term reduction of the UK's CO_2 emissions.

As highlighted in the King Review of Low-Carbon Cars, road based CO_2 emissions reductions will come from a number of different sources including the development of alternative fuels such as hydrogen, the continuing improvements in internal combustion engine efficiency, and lightweighting of vehicles. The review and impact of these has not been considered in this study.

This study has examined a number of factors which will influence the development, uptake and impact of EVs and PHEVs within the UK.

In particular the following have been considered:

- Possible scenarios for the uptake of these vehicles
- Comparison of the life cycle emissions and environmental impacts of these vehicles with petrol/diesel vehicles
- Battery technologies for EVs
- The impact of these vehicles upon the UK electricity grid
- Opportunities to develop UK business in support of vehicle development
- Barriers to be overcome and incentives required to help stimulate the market
- Pilot projects to test and further understand the issues surrounding the mass introduction of these vehicles.

The study has focused primarily on cars and light commercial vehicles as these are the most suitable for the application of EV and PHEV technologies and make up the greatest proportion of UK registered vehicles. The uptake of EVs in the medium term will be centred on urban environments and will start with the city/second car market and local delivery vehicles. PHEVs with their increased range will have greater penetration of the market in the medium term.

1.1 Background

EVs have existed for over one hundred years and have been extensively researched since the 1960s. Concerns about the price and security of oil supply have acted as a spur to EV development and have to some extent heralded a new age of electric transport with oil predicted to become prohibitively expensive or running out altogether. As yet, the EV has not come of age, nor has oil run out, although there is increasing concern that oil supplies are near, or already past, their peak. This suggests that if EVs are to be successful in the market place now significant interventions would be required to overcome the techno-economic barriers which have prevented their more widespread adoption of in the past.

EVs have the capability to deliver sustainable transport and lower CO_2 emissions. A range of configurations are available:

[1] In this study, EV refers to vehicles that derive their energy directly from the electricity grid and store it in on-board batteries.

- **Electric Vehicles (EVs),** using a battery driving an electric motor.
- **Hybrid Electric Vehicles** (HEVs) in which the electric motor works in tandem with a conventional Internal Combustion Engine (ICE). Hybrid vehicles use two configurations:

  Parallel Hybrid, in which the electric motor and ICE both provide drive to the wheels

  Series Hybrid, in which the electric motor provides all of the drive, taking its electricity from the battery and an engine driven generator

Some hybrid vehicles have the ability to recharge their batteries from the grid. These are termed plug-in hybrid vehicles (PHEVs). There are also varying degrees of hybridisation with differing ratios of power coming from the essential elements. A key difference is that HEVs have a very limited electric only capability and do not at any time plug into the grid – hence they are beyond the scope of this study. EVs and PHEVs take some or all of their power from the grid and require infrastructure to support them.

EVs can be viable options as private cars, light goods vehicles (LGVs) and buses, and are particularly attractive in large urban areas. It is hard though to imagine heavy goods vehicles (HGVs) utilising electric-only power due to their mass and duty cycle. As outlined in the King Review of Low Carbon Cars, the future is likely to see a diverse range of fuels, dependent on to the usage pattern of different types of vehicles. In the case of personal transport, which accounts for 67% of all transport energy, this diversity of usage is most apparent. It is possible to foresee a scenario where HGVs and buses would operate on biofuels, gas or in the longer term hydrogen. Local delivery vehicles, with the introduction of consolidation centres, could be predominately electric along with many light goods vehicles.

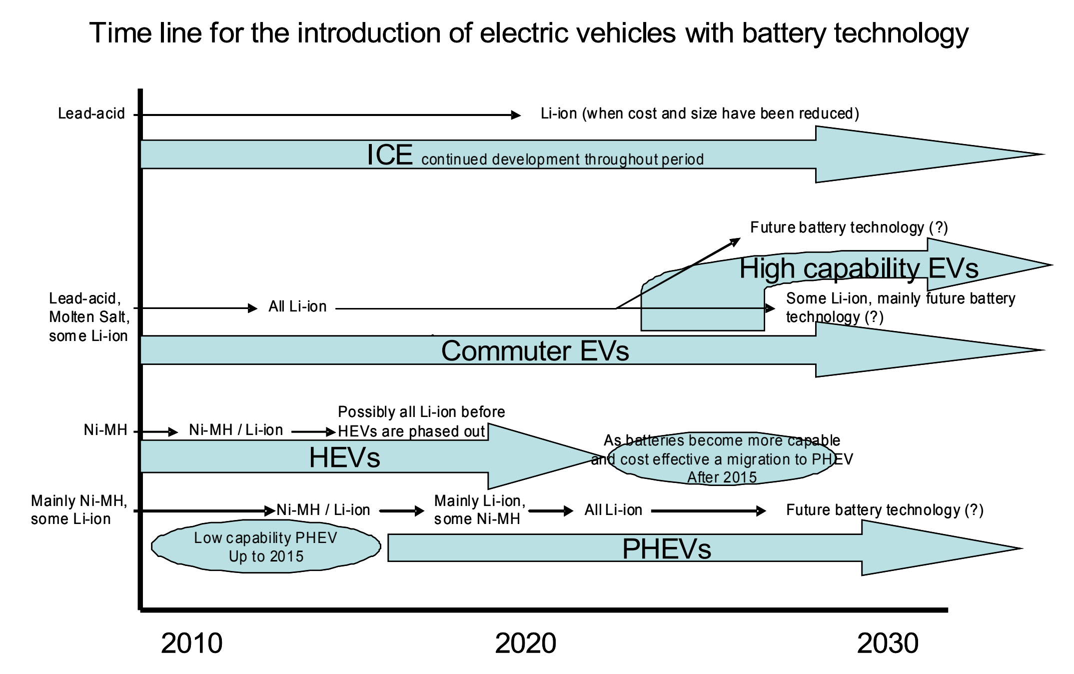
However, privately owned cars pose further problems, not least in their fragmented ownership and usage patterns. The solution to the private car issue may require a shift in expectation and modes of car ownership. One possible answer would be a move to a situation where a buyer purchases a car which is suitable for the vast majority of their requirements and is then content to hire a car or use another form of transport for journeys fall outside of their normal use pattern. Achieving this would require significant intervention into the market place, and a radical change in expectation by the user. Alternatively fast charging or battery replacement options may address range constraints of EVs, although there are issues with both of these approaches (see section 5).

It can be argued that a solution is offered by hybrid cars with extended electric mode range and smarter control systems which operate at zero emissions in urban areas. Such vehicles could have 100% EV capability over a workable but limited range, but as with existing HEVs, they require two motive power systems, and this adds weight and cost. Because of the additional weight of two power units, current hybrid offerings struggle to match the efficiency of modern diesel engines cars in both fuel economy and emissions.

As on-board energy storage improves, higher capability electric cars could lead to an expansion of EV uptake outside of urban areas. However, the availability of EVs offering a range comparable to that of conventionally-fuelled vehicles relies on achieving significant breakthroughs in on-vehicle energy storage and their introduction is not anticipated until at least the end of the period covered by the study.

1.2 Overview of Electric Vehicle Technology Development

The figure below gives an overview of the EV technologies which are likely to be developed over the next 20 years for the global vehicle market, driven by a world market for lower emission vehicles. UK Government interventions will affect vehicle uptake volumes in UK, but will only influence marginally the introduction dates of these technologies.



For EVs to dominate the market without significant intervention they will require similar levels of range and flexibility to those offered by current internal combustion vehicles (ICVs). Offering such high capability EVs will require a step change in battery technology, and because of this, such vehicles will not be seen in the market until the end of the study period. Their effect on the energy requirements in the study time frame will be negligible.

1.3 The Current UK Market

It is useful to understand the size and make up of the current market, both in terms of number of vehicles and journey lengths as this provides a baseline for the understanding of the potential impact of EV uptake.

As stated earlier it is difficult to see pure electric drive being developed for HGVs, and, as buses, coaches and motorcycles account for only a small proportion of vehicle numbers and distance travelled, this study has focused on the largest part of the potential market – namely cars and LGVs.

1.3.1 Vehicle

The 2007 UK vehicle fleet was as follows[2]:

- The total number of vehicles registered in the UK was 33.9 million. This total breaks down as:-

  Cars – 28.2 million (83.2%)

  LGVs – 3.2 million (9.4%)

  HGVs – 528,000 (1.6%)

  Buses and coaches – 181,000 (0.5%)

[2] DfT Vehicle Licensing Statistics 2007

Motorcycles – 1.2 million (3.5%)

Other – 570,000 (1.8%)

- Of the registered vehicles 2,000 were electric cars and 4,000 electric LGVs.
- Of the 2.7 million cars and LGVs registered for the first time approximately 1,000 were electric.
- Approximately 16,000 non plug-in electric hybrids (HEVs) were registered for the first time in 2007.
- There were no electric or hybrid HGVs.

1.3.2 Journey

The total distance travelled by UK vehicles in 2006 was 506.4 billion km[3]. This figure is dominated by passenger car journeys, illustrated by the following breakdown:-

- Cars – 402.4 billion km (79%)
- Light goods – 64.3 billion km (13%)
- Heavy goods – 29.1billion km (6%)
- Buses – 5.4 billion km (1%)
- Motorcycles – 5.2 billion km (1%)

- Motorway journeys (all vehicles) – 99.2 billion km (20%)
- Rural journeys (all vehicles) – 212.3 billion km (42 %)
- Urban journeys (all vehicles) – 194.8 billion km (38%)

- The average car journey was 13.6km and 93% of all car journeys were less than 40km.

[3] DfT Transport Statistics Great Britain 2007

2 Scenarios

2.1 Summary

Four scenarios have been developed for the introduction of electric cars into UK. The scenarios model the car sector as this constitutes the greatest number of vehicles and has the largest impact on grid and CO_2 emissions. This sector is also where the major manufacturers are currently directing their activities in the field of electrification.

The Business as Usual scenario assumes that current incentives are left in place and no additional action is taken to encourage the introduction of electric cars. Battery costs are such that whole life cost parity with conventional cars would not be achieved until around 2020. This would be expected to limit the growth of EVs to congestion zones such as London and amongst green consumers.

The Mid-Range scenario assumes that environmental incentives continue to grow at their current rate. This scenario assumes that whole life costs of an EV are comparable to an ICV by 2015. Sales of EVs are largely restricted to urban areas and by their cost and limited capability whilst PHEVs are limited due to their price premium compared to ICVs.

The High-Range scenario assumes significant intervention to encourage electric car sales. Charging infrastructure is widely available in urban, suburban and in some rural areas. The whole life costs of EVs are comparable with ICVs by 2015 with battery leasing easily obtainable.

The Extreme Range scenario assumes that there is a very high demand for electric cars, with sales only restricted in the short term by availability of vehicles. In the longer term, almost all new vehicle sales are EVs or PHEVs.

These scenarios result in the following uptake.

Number of Vehicles in UK Car Parc						
	2010		2020		2030	
Scenario	**EV**	**PHEV**	**EV**	**PHEV**	**EV**	**PHEV**
Business as Usual	3,000	1,000	70,000	200,000	500,000	2,500,000
Mid-Range	4,000	1,000	600,000	200,000	1,600,000	2,500,000
High-Range	4,000	1,000	1,200,000	350,000	3,300,000	7,900,000
Extreme Range	4,000	1,000	2,600,000	500,000	5,800,000	14,800,000

The impact of these scenarios on carbon dioxide emissions, air quality, electricity demand, and energy storage potential are discussed in the following chapters.

2.2 Methodology

The scenarios do not represent forecasts or estimates of the future, rather they have been built to understand the potential magnitude of electrical energy required over time, the potential CO_2 savings, impacts upon air quality and the potential storage available for Vehicle to Grid schemes (V2G).

Scenarios for both vehicle uptake and energy demand were discussed with the major energy suppliers in the UK and vehicle manufacturers, creating a view regarding the timing of products to market, the vehicle types and volumes. Battery and electricity costs were projected forward and compared with future fuel price to the consumer to understand the time frame in which costs for EVs could become competitive. In addition, consideration was given to public statements by manufacturers and component suppliers, and other published reports.

2.3 General Discussion – Scenarios

The variable costs which influence the market penetration of EVs will be: fuel price, battery cost, electricity costs and market interventions. Of these the battery cost will be both the most significant influence on vehicle price and the one which is least controllable. Battery cost will be determined by a combination of the costs of materials, development, production and shipping, and in the early years there will be limited competition in the sector, driving up prices. As supply increases to match demand and production processes improve with more manufacturers coming to market, prices will reduce. There are many press releases to evidence this growth in production locations and volumes with the big European and American system supply companies forming joint ventures, mainly with Far Eastern manufacturers. This activity also underlines the confidence that the Original Equipment Manufacturers (OEMs) have that there will be a requirement for the output from these factories.

Both the Business as Usual and Mid-Range scenarios envisage the growth of EVs to be in large inner city areas, and therefore it can be argued that they are more easily incentivised in these areas. Outside of these environments both HEVs and PHEVs will be the alternative vehicle choice to conventional powertrains. In the early years HEVs will be cheaper than their PHEV equivalents. PHEVs will initially be premium products where the battery costs will be more easily absorbed. As battery performance improves the electric mode range of PHEVs will increase, displacing the first generation HEVs. This study has found little evidence of any volume PHEV market introduction prior to 2014. It is clear that a number of OEMs are working on limited range PHEVs, but as yet there are no firm launch dates available. Market conditions or widespread incentivisation could affect vehicle volumes after 2014 but not before, as the vehicles will not be available in the market place.

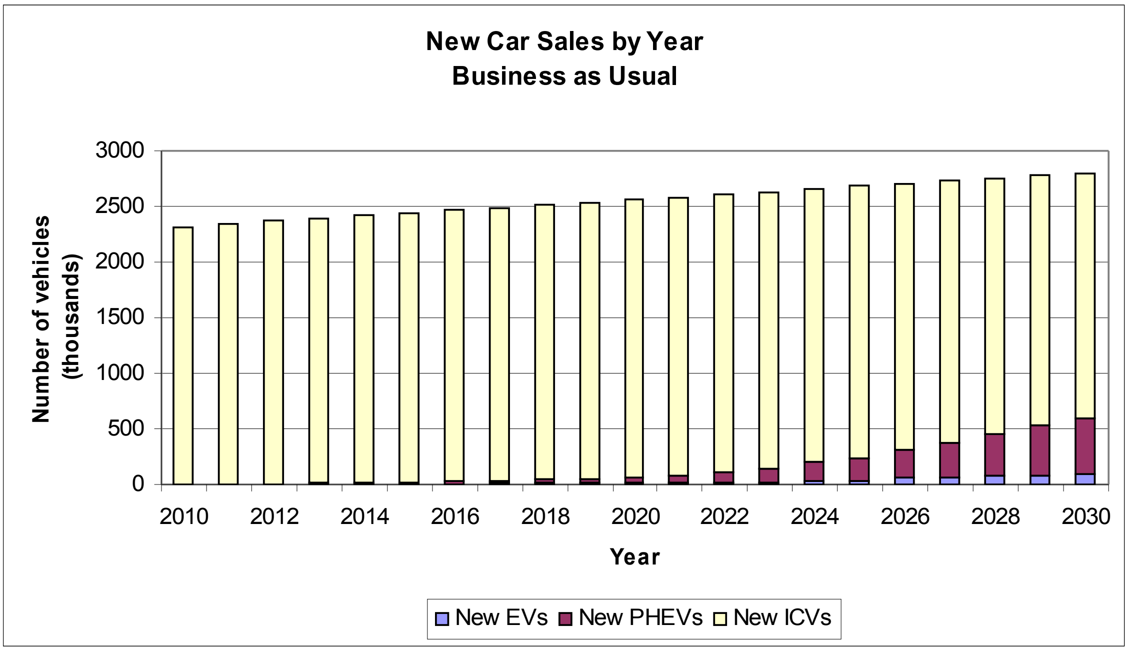
2.4 Uptake Scenarios – Business As Usual

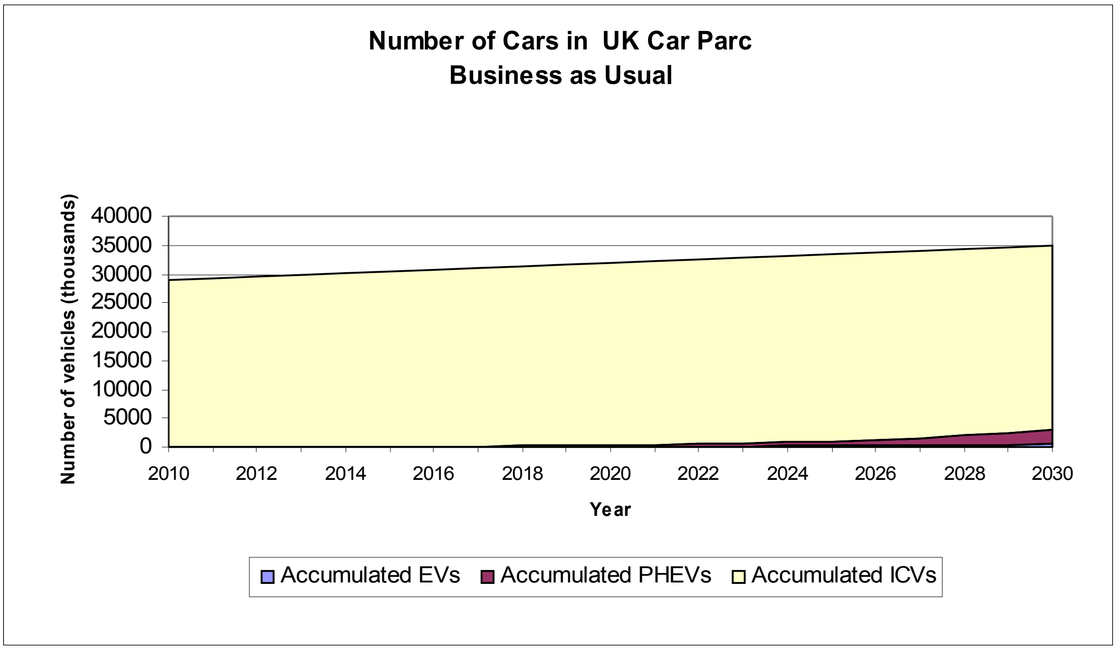
This scenario assumes that no further action is taken to encourage electric cars and that only existing incentives continue. This will limit the growth of electric cars to congestion zones in London and green consumers.

The assumptions regarded as Business as Usual (BaU) are as follows:-

- Congestion charging in London
- Charging points in London and one or two other cities
- Preferential parking places in inner city locations
- VED incentives for low emission vehicles
- Oil to electricity price differential maintained or more favourable to electricity
- Whole life cost parity around 2020.

With the above assumptions, the projected new car sales and consequent changes in the UK vehicle parc are shown below.





The uptake in the BaU scenario is constrained by the cost of EVs and their lack of capability. In this scenario both small ICE cars and HEVs are cheaper and have no limit on their range and performance. A lack of further incentives prevents both the uptake and the introduction of new EV product into the market place; those that are sold are a mix of quadracycles and low volume passenger cars. The projected figures are shown below.

Number of Vehicles in UK Car Parc			
Car type	**2010**	**2020**	**2030**
EV	3,000	70,000	500,000
PHEV	1,000	200,000	2,500,000

After 2014 the major manufacturers commence production of PHEVs, driven by the need to reduce fleet CO_2 averages. Starting in the premium sector, these cars will become more widespread after 2020 as battery costs reduce and consumers see them as real alternatives to ICVs.

2.5 Mid-Range Scenario

This scenario is based on the current trend for environmental measures being maintained, which results in 2.5% of all cars being able to connect to the grid in 2020 and 11.7% by 2030. The scenario includes the continuation of the London congestion charge, which is currently the single most effective intervention in Europe, evidenced by localised high demand for HEVs and L class EVs (quadracycles). In 2009 a fully homologated passenger car (M1 class) EV is expected to enter the market, albeit at a higher price.

This scenario assumes that whole life costs of an EV are comparable to an ICV by 2015. Leasing of batteries is available allowing their capital costs to be amortised over the life of the car.

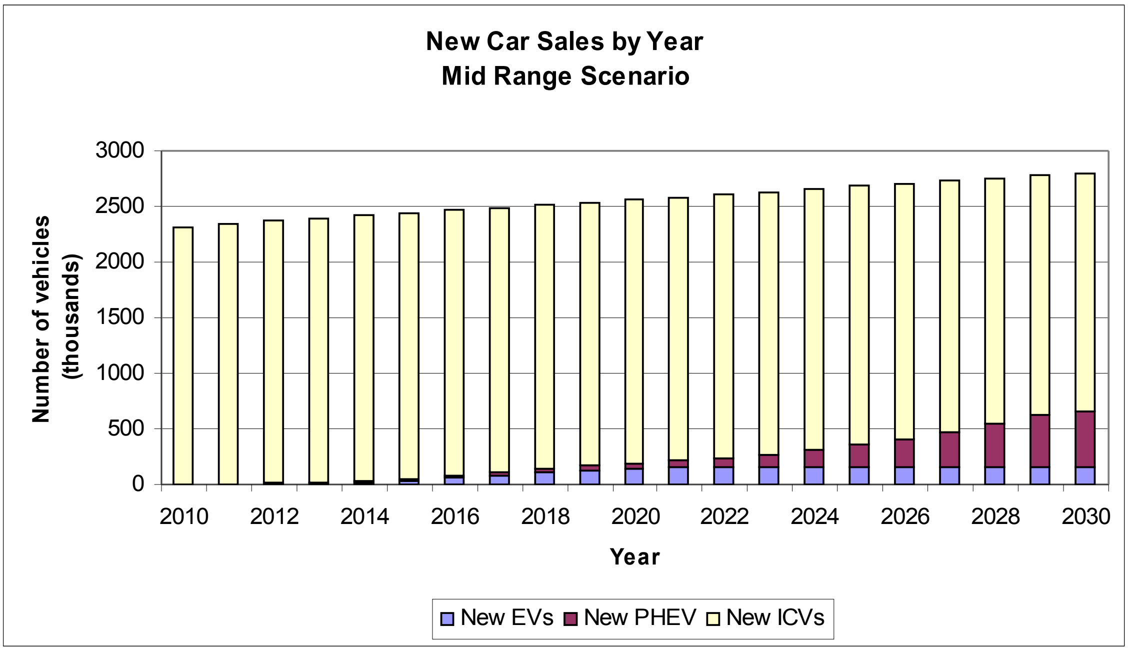
The product development cycle for a new vehicle is typically four to six years. With only a few vehicle manufacturers currently working on large scale volume production of EVs, this means that vehicles are unlikely to appear in large volume before 2014. This scenario is initially supply constrained; it assumes that a number of quality manufacturers will enter the market and make available significant numbers of cars. Following on from the current L class quadracycles, the first M1 (passenger car) vehicle to market is likely to be produced by Think. The volumes of this car intended for the UK market are not known to this study, but are assumed to be around 1,000 in the first year rising to 10,000 by 2015. The next entrant into the market is assumed to arrive in 2012, although it is clear that such a vehicle will need to be currently under development to achieve this date.

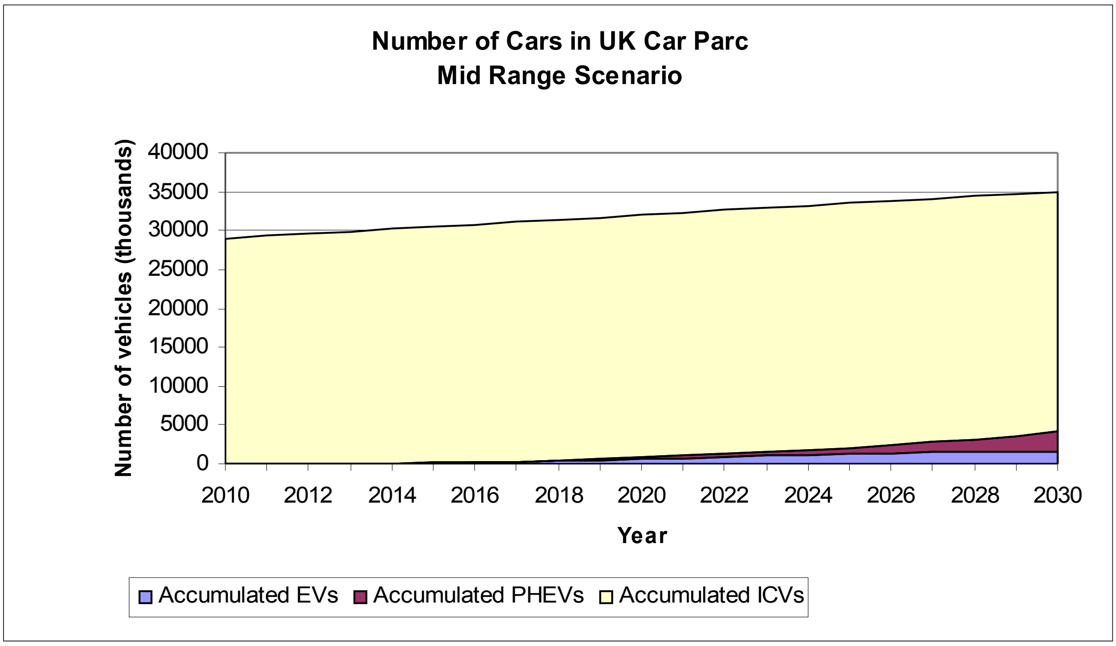
2014 could see the introduction of a car currently at an early concept stage, perhaps incentivised by the publicity surrounding EVs and encouraged by interventions put in place around its target market. It is assumed to be from a major European manufacturer. This scenario envisages another such company following it in 2015 and two more bringing product to market in the following years.

The EVs are projected to be concentrated in the UK's major cities where they suit people's travel needs and where most interventions will be centred. In the UK, 7,000,000 vehicles are owned in the UK's five biggest cities so the projected total in 2030 of 1,600,000 could be regarded as aggressive.

In addition to EVs there will be PHEVs coming to market. Toyota announced in September 2008 that it will offer a PHEV version of the Prius. Whilst no plans are known in detail to this study, it is probable that another major manufacturer such as GM will bring a PHEV to market by 2014, soon followed by a number of others. Due to PHEV costs and the lack of strong incentives envisaged in the Mid-Range scenario, the volumes would not be high. Whilst 200,000 in 2020 may not seem many, the momentum will be with PHEVs and 2,500,000 units by 2030 could be achievable as battery and whole life costs reduce.

With the above assumptions, the projected new car sales, and the consequent changes in the UK vehicle parc are shown below.





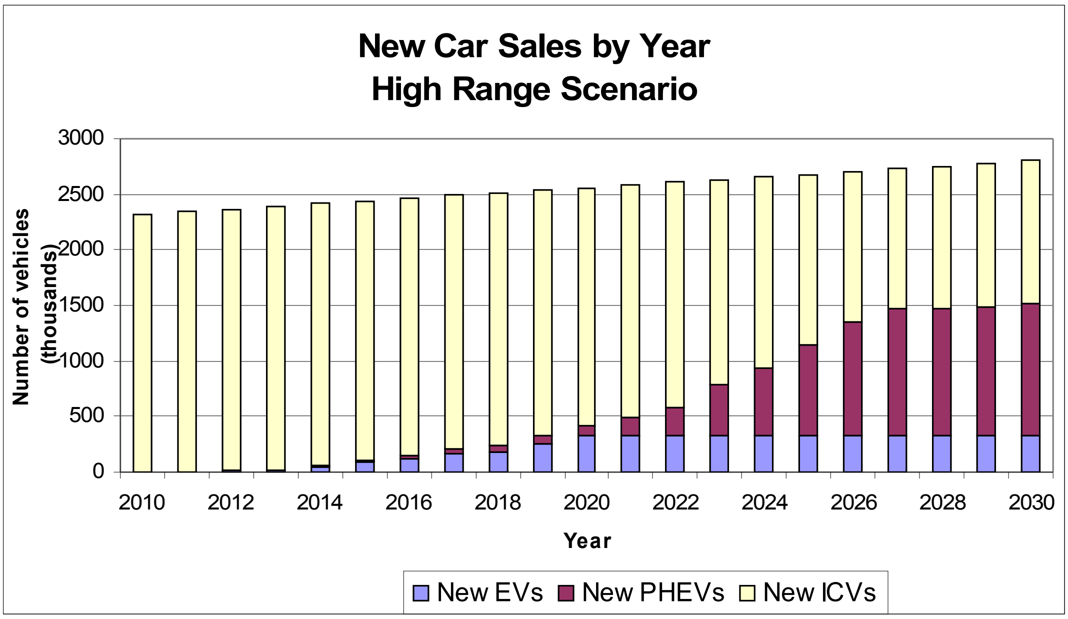
Number of Vehicles in UK Car Parc			
Car type	**2010**	**2020**	**2030**
EV	4,000	600,000	1,600,000
PHEV	1,000	200,000	2,500,000

2.6 Uptake Scenario – High-Range

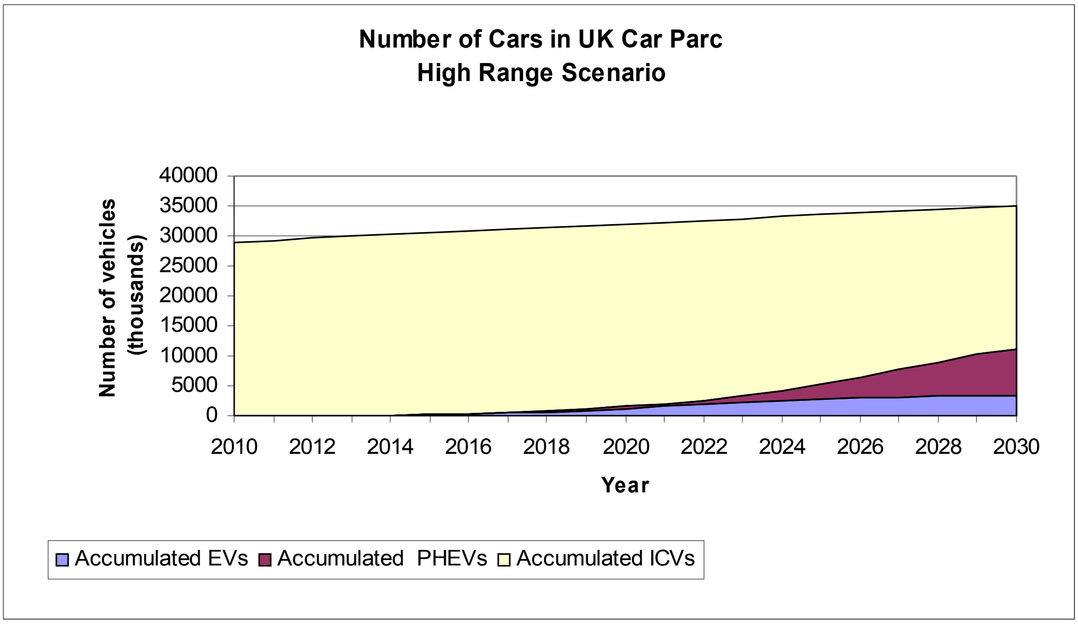
This scenario relies on the UK government wanting to position the country as a world leader in low carbon car use, manufacture and development, and that a mix of technologies will be developed to achieve this. It is assumed that whole life costs of EVs will attain parity with conventional cars by 2015. The scenario results in 4.9% of the UK car parc being able to connect to the grid by 2020 and 32% by 2030. There is no change compared to the Mid-Range scenario prior to 2014, as the numbers remain constrained by the lack of vehicle availability. To achieve the level of production and sales demanded by this scenario, market conditions and necessary infrastructure to support the rollout of grid-connected vehicles, particularly PHEVs, beyond urban areas will need to be in place. The period after 2020 will need to see significant decreases in the cost of EV ownership, particularly batteries, and an increase in the range of vehicles available to consumers in order to sustain the growth momentum.

To achieve such vehicle numbers, manufacturers will need to see a clear vision for both the UK and Europe that makes the volumes viable. At this time it is not understood how zero tailpipe emission vehicles will be treated under the proposed CO_2 regulatory framework. Some manufacturers have suggested "super credits" by which electric cars count as more than one unit when considering the fleet average. Proposals such as this should be considered in detail as they could act as a considerable incentive to the development of electric cars in volume. It should be noted that no large manufacturer will produce a car in volume for the UK alone, and as such grid-connected cars will need to be incentivised in other countries.

With the above assumptions, projected new car sales, and the consequent changes in the UK vehicle parc are shown below.

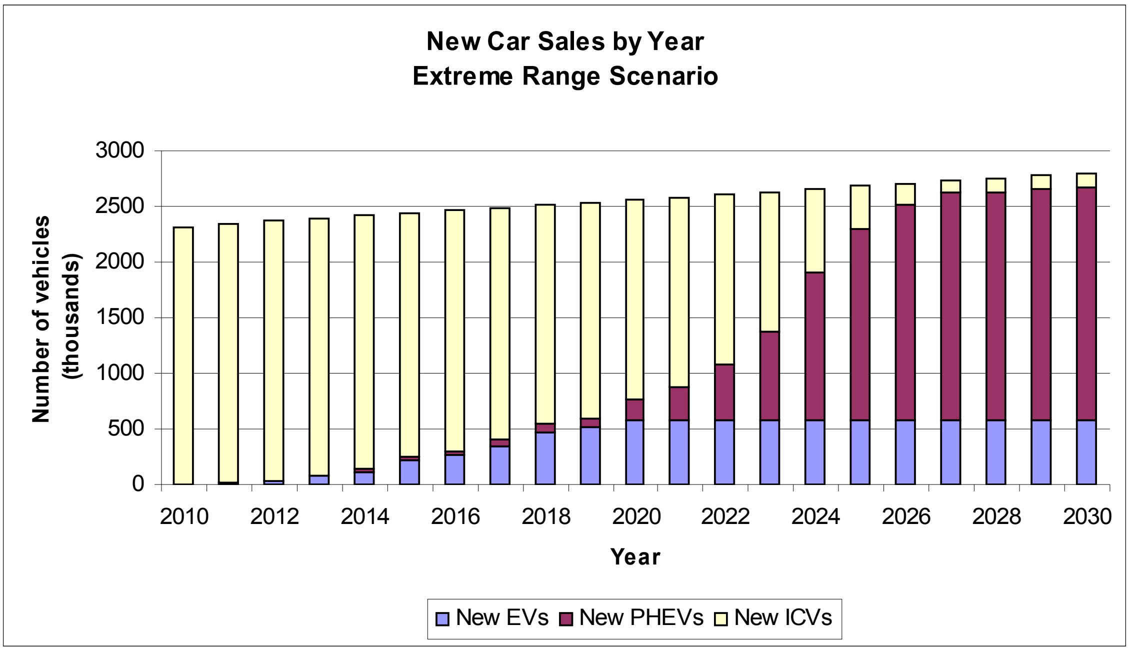


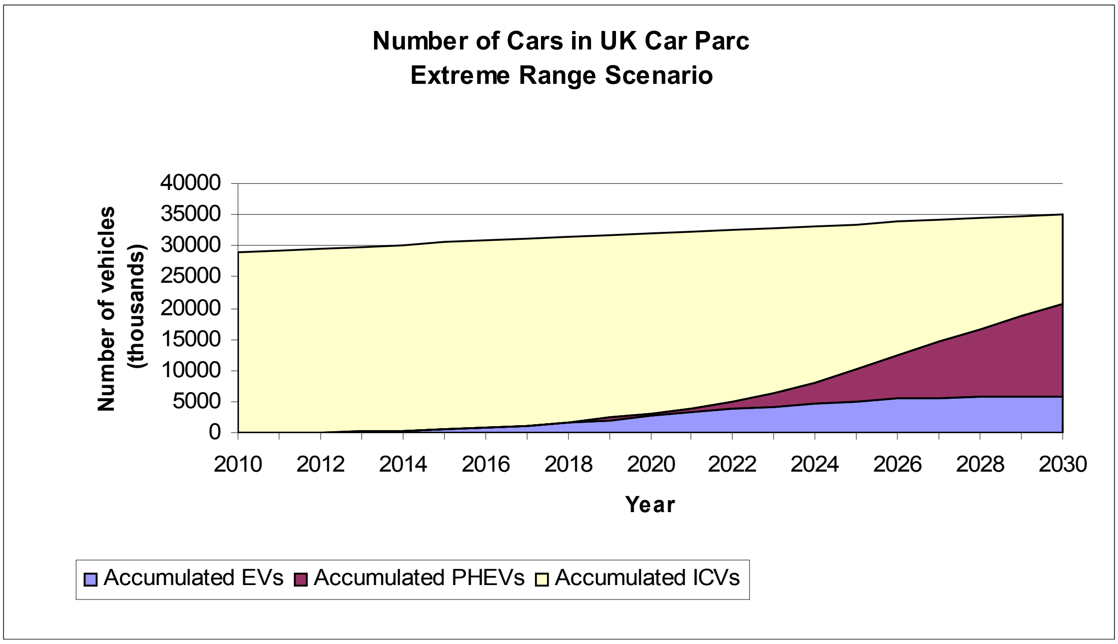
Number of Vehicles in UK Car Parc			
Car type	**2010**	**2020**	**2030**
EV	4,000	1,200,000	3,300,000
PHEV	1,000	350,000	7,900,000



2.7 Uptake Scenario – Extreme Range

This scenario sees total dominance of grid connected cars to achieve a low carbon future, with 10% of all cars being able to connect by 2020 and 60% by 2030. Whilst this is an extreme premise it is possible assuming a renewal of a maximum of 8% of the car parc by new cars each year. Again due to supply constraints the uptake prior to 2014 is similar to the previous scenarios, but after this date it becomes increasingly less constrained as more products comes to market across Europe. This extreme scenario would require almost all new cars purchased to be grid-connected after 2025.





Number of Vehicles in UK Car Parc			
Car type	**2010**	**2020**	**2030**
EV	4,000	2,600,000	5,800,000
PHEV	1,000	500,000	14,800,000

3 Comparison of Life Cycle Emissions and Environmental Impacts of EVs and ICVs

3.1 Summary

- On a full life cycle basis, taking account of emissions from power generation, and emissions relating to production and disposal, EVs have the potential to offer significant carbon dioxide and greenhouse gas emissions reductions over time compared to conventional petrol/diesel fuelled ICVs. An example is shown below. These savings have the potential to become much greater with further decarbonisation of the UK power mix.

	Vehicle Manufactured in 2010			
	Electric		ICV	
	GaBi 4[4] factors grid mix	Defra long term marginal factor[5]	Petrol	Diesel
Emission factor (well to wheel) gCO_2e/km	106	69	172	156
Lifetime vehicle carbon use kg CO_2 - equiv	19,161	12,384	30,916	28,012

- While there may be some additional carbon dioxide emissions associated with the production and disposal of EVs, as with conventional vehicles, the majority of life cycle emissions are associated with the usage phase.
- EVs offer benefits of improved air quality in urban areas through zero tailpipe emissions of NO_x, SO_x and particulates. However, overall emissions of NO_x and SO_x may be higher with EVs as a result of power sector emissions (principally from coal plant) – with some potential negative consequences for air acidification. These impacts would reduce over time if greater proportions of renewable power, and reduced amounts of coal generation, become a feature of the UK power mix,
- Water consumption is higher with EVs – this is again a feature of the increased power generation associated with charging EVs. This additional water consumption is relatively modest compared to a typical UK household's water consumption.
- There are a range of potential environmental issues associated with the production, use and disposal of lithium-ion (Li-ion) batteries which require further investigation. If properly managed these issues should not prevent their widespread safe use in automotive applications.

[4] GaBi 4 is a Life Cycle Assessment tool conforming to the ISO 14040 Life Cycle Assessment (LCA) standards. It is designed to allow the user to model the whole life cycle (or part) of a product or service, and provides a quantitative output on a range of environmental impacts.

[5] The Defra long term marginal factor "assumes that, over a long time period (a decade or more) avoided electricity use will displace generation at a new Combined Cycle Gas Turbine (CCGT) plant" (Defra; Guidelines to Defra's GHG Conversion Factors; 2008.

3.2 Climate and Air Quality Impacts

This section considers the following:

- *Climate Change* – the potential for greenhouse gas emissions released during the lifetime of the vehicle to contribute to global warming.
- *Air Acidification* – the potential for emissions of acidic gases (such as sulphur oxides and nitrogen oxides) to contribute to 'acid rain'.
- *Photochemical Oxidant Formation* – also known as 'summer smog' this is the reaction of NO_x and volatile organic compounds with UV light.

3.2.1 Climate Change

Two modelling exercises have been carried out for climate change, which are as follows:

- A comparison of an EV and ICV over the vehicle life (defined as 180,000 km).
- A comparison of the carbon dioxide emissions savings as a result of different levels of take up of EVs and PHEVs (defined as Business as Usual, Medium, High and Extreme in Section 2) in 2010, 2020 and 2030, relative to UK transport emissions in 1990 (the baseline year for Kyoto).

The methodology used is described in Appendix A.

3.2.1.1 Comparison of an EV and an ICV over the Vehicle Life (defined as an 180,00km)

On a comparable basis taking into account both electricity generation and the processes necessary to deliver petrol and diesel to the vehicle, emission factors and lifetime carbon use have been calculated for vehicles manufactured in 2010, 2020 & 2030. For ICVs the addition of pre-combustion emissions (extraction, refining, transport, etc) typically adds another 10-18% to the "tank to wheel" figure. The table below presents these well to wheel figures.

Vehicle Manufactured in 2010				
	Electric		ICV	
	GaBi 4 factors grid mix	Defra long term marginal factor	Petrol	Diesel
Emission factor well to wheel gCO_2e/km	106	69	172	156
Lifetime vehicle carbon use kg CO_2 - equiv	19,161	12,384	30,916	28,012
Vehicle Manufactured in 2020				
Emission factor well to wheel gCO_2e/km	56	56	144	130
Lifetime vehicle carbon use kg CO_2 - equiv	10,132	10,062	25,864	23,435
Vehicle Manufactured in 2030				
Emission factor well to wheel gCO_2e/km	41	47	120	109
Lifetime vehicle carbon use kg CO_2 - equiv	7,390	8,514	21,639	19,606

From the table above it can be seen that EVs use significantly less carbon dioxide than ICV vehicles over their lifetime and that the savings increase as renewables become a greater part of the grid mix. By 2030 CO_2 equivalent emissions for an EV could be one third that of a petrol vehicle.

The 2010 emission factor for EVs based on the Defra long term marginal factor broadly validates the 77 gCO_2/km reported by E4 Tech[6]. These differences arise from different input assumptions about the electricity mix and CO_2 emissions of power generation rather than different calculation methodology.

It should be noted that the above figures are for "well to wheel" emissions, and cannot be directly compared to the tailpipe or "tank to wheel" emissions used for the new car CO_2 emissions targets. The figures are also for comparison of EV and ICV emissions for a specific class of car, whereas the targets are for fleet average emissions.

3.2.1.2 Comparison of CO_2 Savings for the Scenarios for Uptake of EVs and PHEVs

The table below summarises the in-use carbon dioxide savings using the earlier defined scenarios and reflects these savings as a percentage of the overall carbon dioxide emissions in UK from road transport in 1990[7], taken as 109.4 million tonnes[8]. Using a 2006 baseline of 120.3 million tonnes, the percentage reductions would be slightly lower.

The EV "emissions" are based on electricity generated with a carbon dioxide emission factor of 0.43kg CO_2/kWh, the Defra long term marginal factor for the National Grid. This factor could be pessimistic if significant progress is made on the introduction of renewables into the grid mix.

Defra long term marginal factor	**CO_2 saving (T)** *(% of 1990 UK Road Transport CO_2 Emissions)*		
Scenario	**2010**	**2020**	**2030**
Business as Usual	6,000 *(0.005%)*	261,000 *(0.24%)*	2,276,000 *(2.08%)*
Mid-Range	8,000 *(0.007%)*	1,053,000 *(0.96%)*	3,708,000 *(3.39%)*
High-Range	8,000 *(0.007%)*	2,088,000 *(1.91%)*	9,495,000 *(8.68%)*
Extreme Range	8,000 *(0.007%)*	4,361,000 *(3.99%)*	17,254,000 *(15.77%)*

The ICV emissions include both the tailpipe emissions ("tank to wheel") and pre-combustion emissions ("well to tank") required to get the petrol/diesel to the car (extraction, refining, transport, etc). These "well to tank" emissions typically contribute another 10-18% to the climate change impact of the petrol/diesel car.

The carbon dioxide emissions for the EV (and electric portion of PHEV usage) can be modelled either on the assumption that it is the marginal

[6] A Review of the UK Innovation System for Low Carbon Road Transport Technologies, E4tech, March 2007.
[7] 1990 is the baseline year used as the basis for definition of emissions targets by industrialised nations under the Kyoto Protocol.
[8] DEFRA website; e-Digest Statistics about: Climate Change.

power station (a Combined Cycle Gas Turbine (CCGT)) which is generating the electricity required to power the vehicle, or a standard UK grid mix (taking into account distribution losses from the National Grid).

In addition, in this report, greenhouse gas emission savings have been determined using calculated emissions factors for the UK National Grid supplying the EV, based on the projected fuel mix in 2020 and 2030. These calculations, which include pre-combustion emissions outside the UK, reinforce our finding that there is a greenhouse gas benefit to the use of EVs instead of petrol/diesel cars (table below).

GaBi	**CO_2 saving (T)** *(% of 1990 UK Road Transport CO_2 Emissions)*		
Scenario	**2010**	**2020**	**2030**
Business as Usual	4,000 *(0.004%)*	268,500 *(0.25%)*	2,548,800 *(2.33%)*
Mid-Range	5,100 *(0.005%)*	1,084,400 *(0.99%)*	4,152,000 *(3.80%)*
High-Range	5,100 *(0.005%)*	2,151,000 *(1.97%)*	10,631,000 *(9.72%)*
Extreme Range	5,100 *(0.005%)*	4,492,800 *(4.11%)*	19,318,900 *(17.66%)*

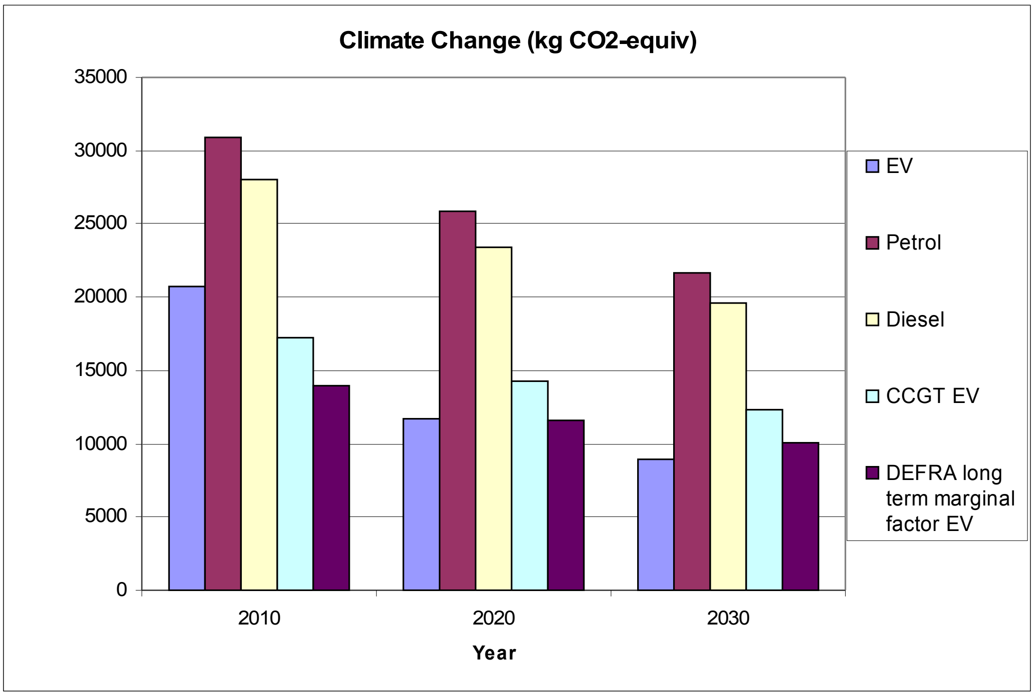
Business as Usual and Mid-Range scenarios provide a small carbon dioxide saving of less than 1% by 2020 and less than 3.4% by 2030, relative to 1990 transport emissions.

Significant emissions reductions are achieved for the High-Range and Extreme Range in 2030.

Emissions reductions in any scenario in 2010 are not significant.

3.2.1.3 Comparison of Climate Change Impacts for EVs and ICVs

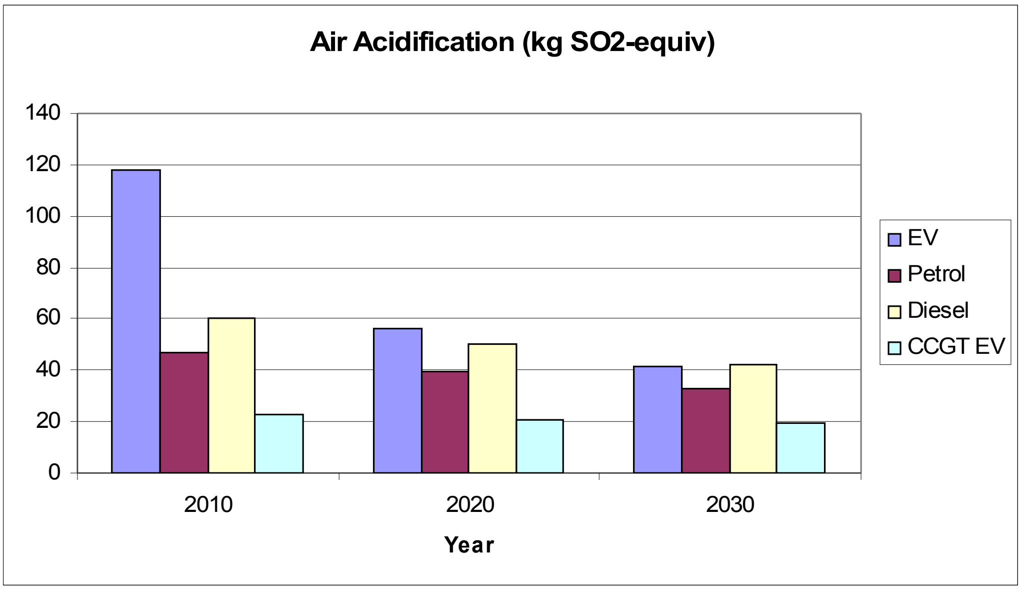
This analysis compares an EV with a petrol and diesel ICV travelling 180,000 km in its lifetime.



- The climate change impact of the EV is 53% less than the impact from an average ICV (50% petrol, 50% diesel) in 2020. This is markedly higher than a 30% saving for 2010 and slightly lower than the calculated saving for 2030 of 57%.
- Use of Defra's long term marginal factor increases the saving to 50-55% in 2010. When pre-combustion is included, this reduces to 39-44%.
- EVs have no tailpipe emissions of greenhouse gases. However, greenhouse gases are emitted from the fossil fuel power stations supplying the UK National Grid, as well as emissions from pre-combustion sources (extraction of fossil fuels, transport). As the grid mix moves towards a greater contribution from low carbon sources of power generation in line with Government targets, the climate change impact of the EV decreases relative to its ICV equivalent.
- The climate change impact is a result of combustion of fossil fuels. For the ICVs, this combustion occurs in the engine of the vehicle ("tank to wheel" emissions) together with further combustion required to get the fuel to the vehicle (extraction, refining, transport etc). These "well to tank" emissions typically contribute another 10-18% to the climate change impact of the ICV.
- For all scenarios except the "Defra long term marginal factor EV", we have used life cycle emissions factors (which are available in the GaBi 4 database) to calculate the climate change impact of the EV. These take into account pre-combustion emissions, much of which occur outside the UK boundary, and are therefore higher than emissions factors published by Defra.
- Emissions savings for the EV are calculated taking into account improvements in efficiency of ICVs, reflected in the fuel required per km figures in Appendix A. Faster improvements in the efficiency of ICVs would reduce, though not completely remove, the scale of carbon benefits arising from a switch to EVs in 2020/2030. The European Commission is seeking to introduce a 130 g/km tailpipe emission limit on new cars from 2012 and the UK is committed to a long term target to reduce climate change impacts. The treatment of EVs within this proposed regulatory framework is a key issue in order to ensure that full benefits of EVs are captured.
- Extraction of materials to make the battery for the EV contributes 13% to the overall EV climate change impact in 2020. This does not take into account emissions associated

with cell manufacture which will be a function of the energy demands of the process and the energy sources used in the countries of manufacture. Typically, the assembly of the battery which will take place in the UK should not add more than 1% to the whole life energy consumption of the car.

3.2.2 Air Acidification



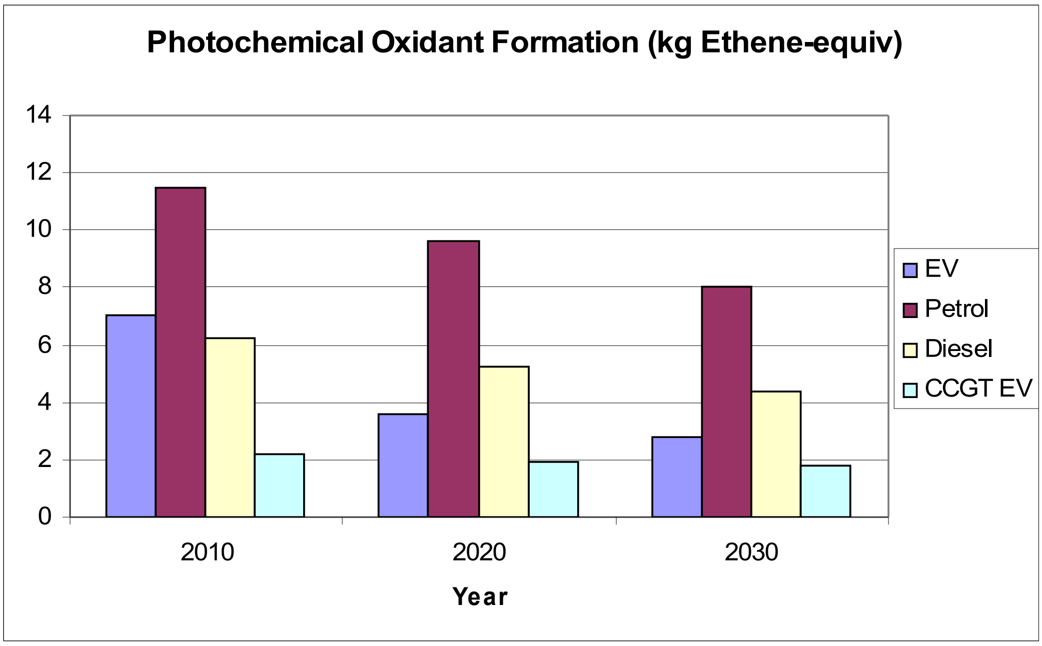
- The above chart does not include the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change.
- The air acidification impact of the EV is significantly higher than the ICV in 2010, reflecting the greater combustion of fossil fuels supplying the UK National Grid required to charge the EV. This impact reduces markedly and is comparable with ICV results in 2020 and 2030, due to greater use of renewables and nuclear energy supplying the National Grid.
- Whilst the air acidification impact of the EV is substantially higher in 2010, there are no tailpipe emissions of sulphur oxides or nitrogen oxides, which could potentially help to achieve better air quality in urban environments. The higher impact associated with the EV is due to fuel extraction, transport and combustion at fossil fuelled power stations (particularly coal).
- Extraction of materials to make the Li-ion battery is calculated to be approximately 12% of the impact from use of the EV in 2010. This impact occurs outside the UK if batteries are imported from countries such as China, Japan and Korea, as is currently the case.
- PHEVs will have tailpipe emissions, when the petrol or diesel motor is operating to charge the battery. The degree of impact of the PHEV is dependent on how much time the motor is charging the battery and how much electricity needs to be taken from the National Grid.
- Air acidification is largely due to emissions of gases such as sulphur oxides, nitrogen oxides and ammonia.

It is recognised that future legislative factors (particularly those associated with air quality) may influence the proportion of electricity obtained from conventional fossil generation. Capital investment supporting conformity to the European Union Large Combustion Plant Directive (LCPD) (which aims to reduce acidification, ground level ozone and particulates by controlling the emissions of sulphur dioxide, oxides of nitrogen and dust from large combustion plant) may be prohibitive to certain existing conventional plant which may be closed by 2015.

All combustion plant built after 1987 must comply with the emission limits in LCPD and those in operation before this date (existing plant) can either install abatement technology in the form of flue gas desulphurisation (FGD) technology or opt out (which will mean restricted operation post 2007 and closure by 2015). At this stage, it is not possible to determine all plant which may close by 2015.

Furthermore, the impact that LCPD may have on utility investment in FGD (rather than closure of existing plant) is unknown. Clearly, LCPD will enforce a reduction in emissions of sulphur dioxide, oxides of nitrogen and dust from large combustion plant. These enforced reductions may have an effect on our modelled emissions forecasts for these compounds, particularly within our forecasts for 2020 onwards, improving the performance of EVs.

3.2.3 Photochemical Oxidant Formation



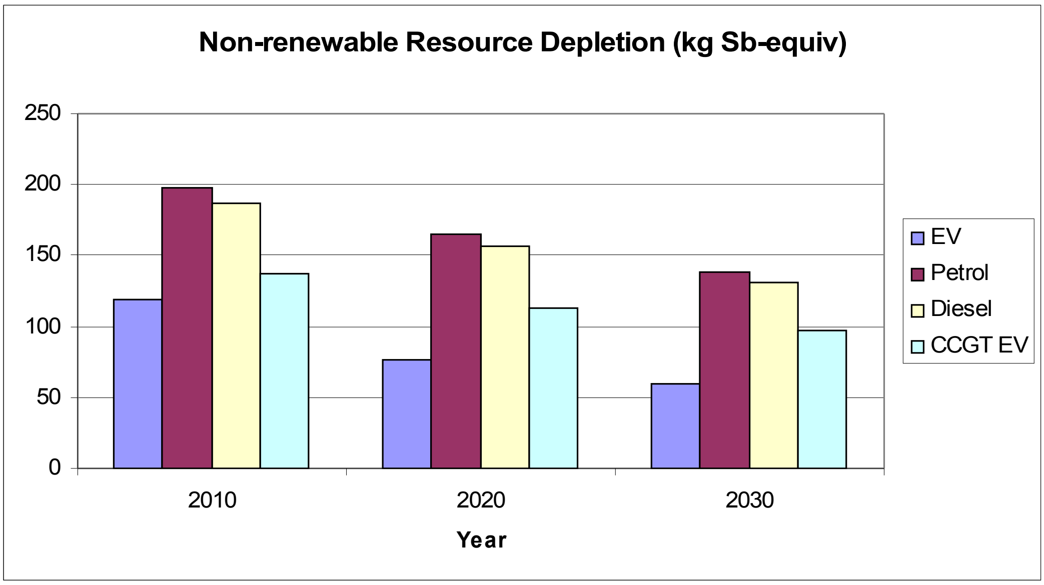
- The above chart does not include the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change.
- The EV has a comparable photochemical oxidant formation impact to the diesel ICV in 2010, and is significantly better than the petrol ICV. By 2020, the EV produces a lower impact than the petrol and diesel ICV.
- The majority of ICV emissions (carbon monoxide and non-methane volatile organic compounds) occur at the tailpipe (56% for diesel, 60% for petrol), meaning these emissions can occur in more sensitive environments, such as urban areas. EV emissions occur at the power stations supplying the Grid, and are therefore further away from urban centres.

3.3 Resources and Waste

This section considers the following:

- *Non-Renewable Resource Depletion* – the potential for non-renewable resource depletion during the lifetime of the vehicle.
- *Water Use* – the amount of water required during the useful life of the vehicle.
- *Waste Generation* – the material disposed by the processes required to keep the vehicle operational during its useful life.

3.3.1 Non-Renewable Resource Depletion

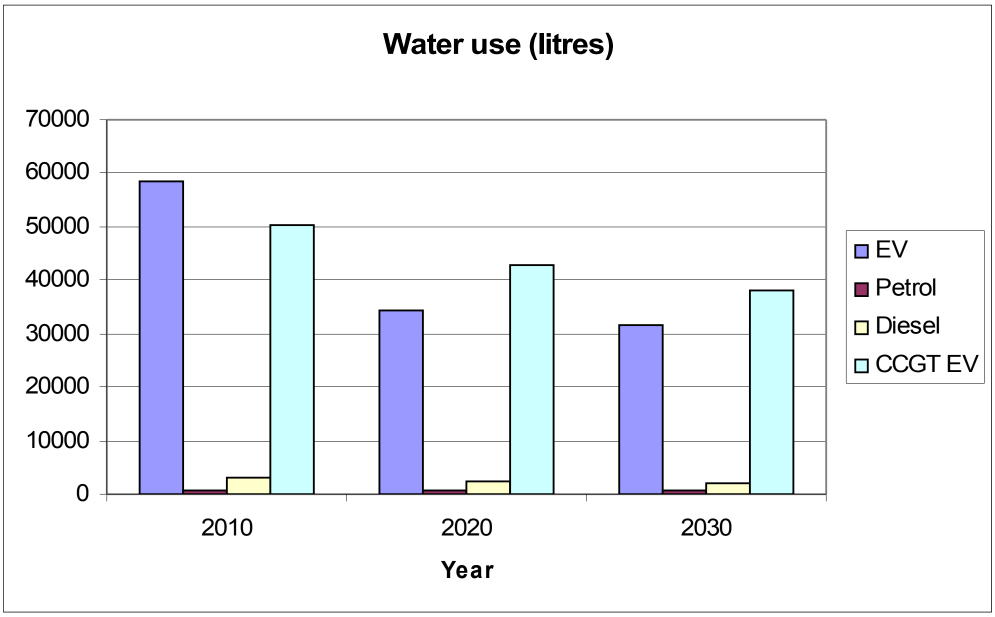


- The above chart does not include the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change.
- The EV has a lower non-renewable resource depletion impact compared to the ICV across all assessed years. This is based on current levels of extraction and known exploitable reserves.
- The main resources contributing to this impact are fossil fuels (primarily oil and natural gas for the petrol/diesel car and oil, natural gas and coal for the EV).
- For the EV in 2010, the contribution to resource depletion as a result of extraction of materials for the battery is 8% rising to 12% and 16% in 2020 and 2030. This is due to a greater proportion of renewables supplying the UK grid.
- There has been some recent commentary concerning the potential impact of increased production of lithium-ion batteries on lithium availability and prices[9]. A report from the USGS (US Geological Survey)[10] on lithium reserves states that there is a world reserve of 4.1 million tons with a reserve base of 11 million tons. This means that 4.1 million tons are economically recoverable, with the remainder being proven geological reserves, but not necessarily economic to recover at the present time. John Searle of Saft, a supplier of lithium cells to the automotive industry, is quoted in Automotive Engineer[11] magazine saying that the quantity of lithium in a lithium-ion battery is countable in just a few grams (comprising less than 2% of the battery weight), implying that lithium used in batteries has a minimal impact on reserves even if production was to be scaled up.
- The issue of lithium depletion could potentially be mitigated if it is possible to recycle successfully the lithium from end-of-life batteries back into a material that can be used in new lithium-ion batteries. Currently no information or data that indicates if this is possible/plausible has been found, although researchers for CSIRO in Australia have developed a novel concept for an improved solvent extraction process to recover and purify cobalt and lithium from batteries[12]. No European Li-ion battery recycling facilities

[9] See for example "An abundance of Lithium" by R. Keith Evans and http://www.guardian.co.uk/technology/2008/jul/31/motoring.energy
[10] U.S. Geological Survey, Mineral Commodity Summaries, January 2007
[11] Article can be found in the July/August 2008 edition
[12] http://www.sciencealert.com.au/features/20082802-16962.html

process the material to obtain lithium – instead the outputs of recycling go into glass manufacture primarily to lower the melting temperature, but also as a strengthening agent.

3.3.2 Water Use

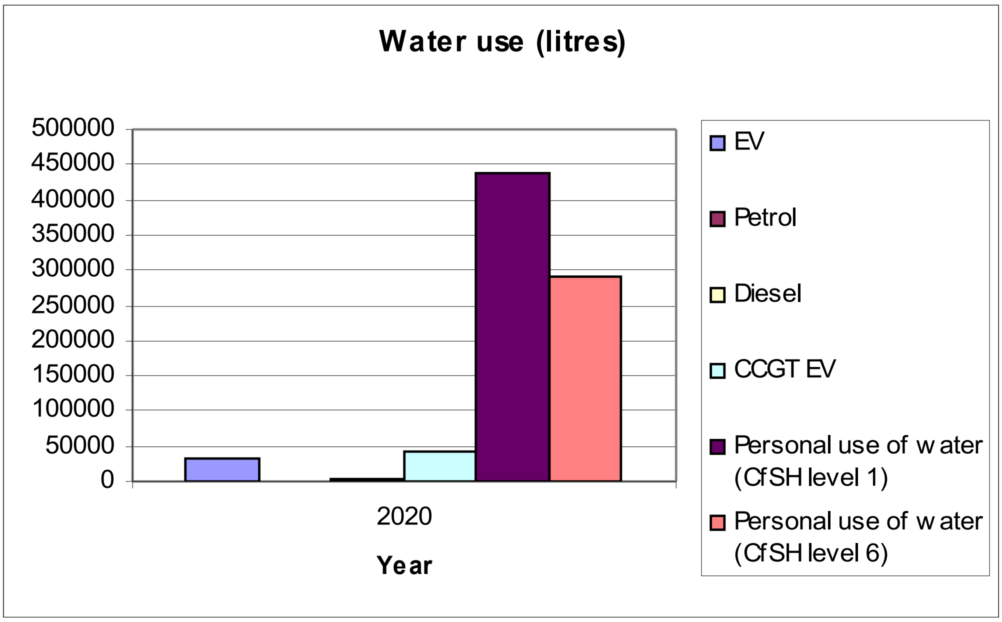


- The above chart does not include the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change.
- Consumption of water by EVs is high in comparison with ICVs as a consequence of the need for cooling at power stations (fossil fuel and nuclear) supplying the National Grid.
- Water used to extract materials for the Li-ion battery amount to nearly 33% of water consumed during use of the EV in 2020. This is primarily due to water consumption to refine lithium salts, which would occur outside the UK. The majority of the water used for lithium extraction (approximately 87%) is returned after lithium is removed[13].
- Comparison of EV water use with internal potable domestic water consumption[14] guidelines in the Code for Sustainable Homes[15] over the 10 year life of the vehicle, shows that the EV figure is significantly lower by comparison (see figure below), and in addition the water required to power the EV is largely untreated (ie river) water, rather than of potable quality as produced for personal consumption.

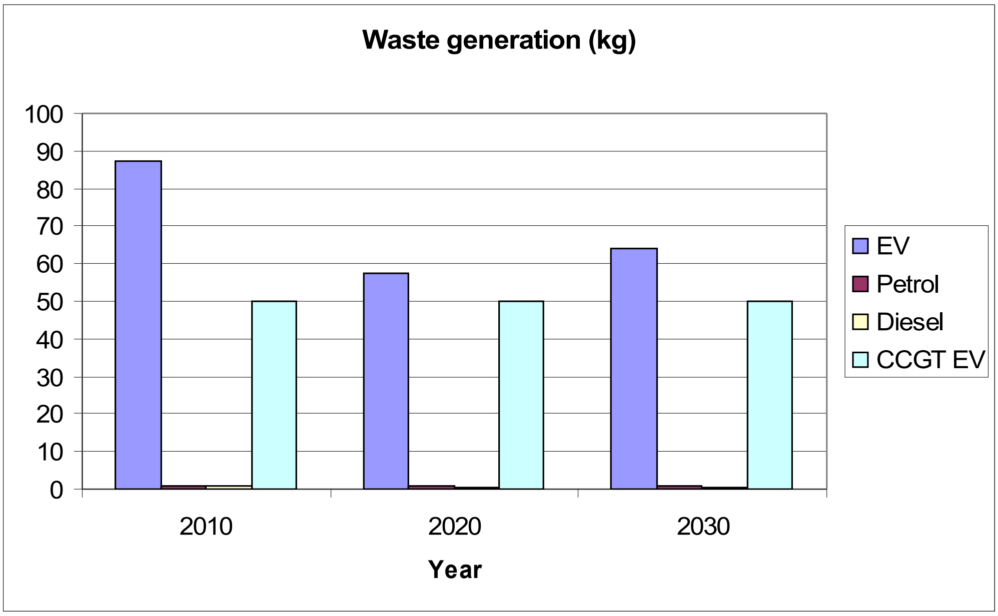
[13] Data sourced from Lithium production in GaBi 4.

[14] This water consumption is based on domestic use only, and does not include water that is indirectly used outside the home, eg. due to cooling at power stations supplying electricity to the home.

[15] CLG; Code for Sustainable Homes – A step-change in sustainable home building practice; December 2006



3.3.3 Waste



- The above chart does not include the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change.
- The EV produces significantly more waste (excluding overburden[16]) than the ICV.
- The in-use waste arises primarily from radioactive waste from the nuclear industry component supplying the Grid. This should be viewed in the context of the predicted requirement for electricity to charge EVs in 2020, which amounts to 1% demand or less (for the Business As Usual and Mid-Range scenarios).
- Most of the waste produced by the EV arises during extraction of materials to make the batteries (57-86%) which occurs outside the UK.

[16] Material temporarily set aside during mining operations.

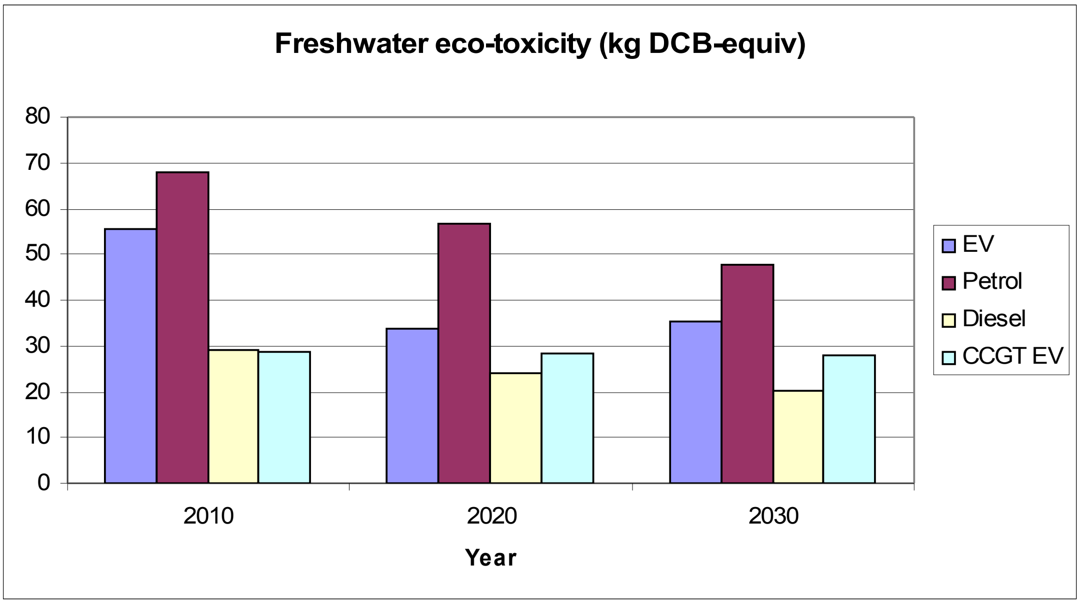
- If overburden is included in the analysis, it makes up more than 99% of the waste produced for both the EV and ICV. As it comprises material that is temporarily moved during mining operations, but remains within the mine boundaries, it is not considered in this analysis.

3.4 Impacts to Water

The impacts considered in this section are as follows:

- *Aquatic Ecotoxicity (Freshwater)* – the study of how chemicals affect the water environment and the organisms living there.
- *Eutrophication* – the absorption of excessive nutrients in a body of water, which causes a dense growth of plant life; the decomposition of the plants depletes the supply of oxygen in the water, leading to the death of animal life.

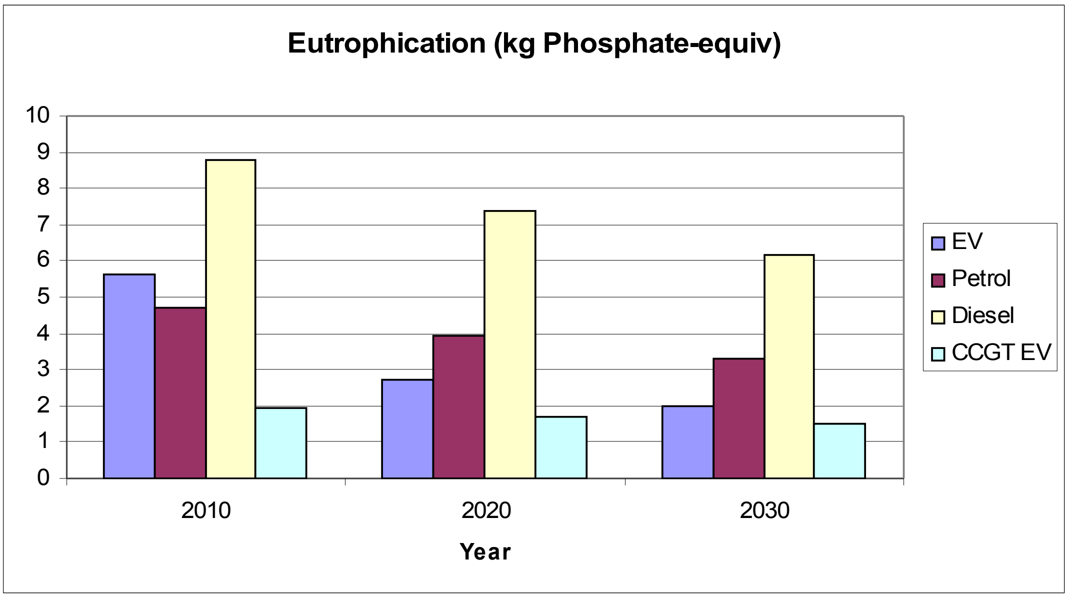
3.4.1 Aquatic Ecotoxicity (Freshwater)



- The above chart does not reflect the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change
- Potential freshwater eco-toxicity impacts for the EV and ICV (petrol and diesel combined) are comparable. 79% of the EV impact arises from extraction of materials for the batteries, which is likely to occur outside the UK
- EV in-use impact is markedly lower than for the ICV (18%). As the renewable portion of the grid increases, the EV impact falls.
- Over 99% of the impact from petrol and diesel comes from production of the fuels.
- Leakage of electrolyte from batteries after an accident, or through unsuitable disposal, could potentially contaminate water and have a detrimental effect on the environment due to the hazardous metals in their make-up[17]. Further assessment, particularly as a result of an accident situation, is recommended.

[17] http://www.deq.state.ms.us/MDEQ.nsf/page/Recycling_BatteriesFAQs?OpenDocument

3.4.2 Eutrophication



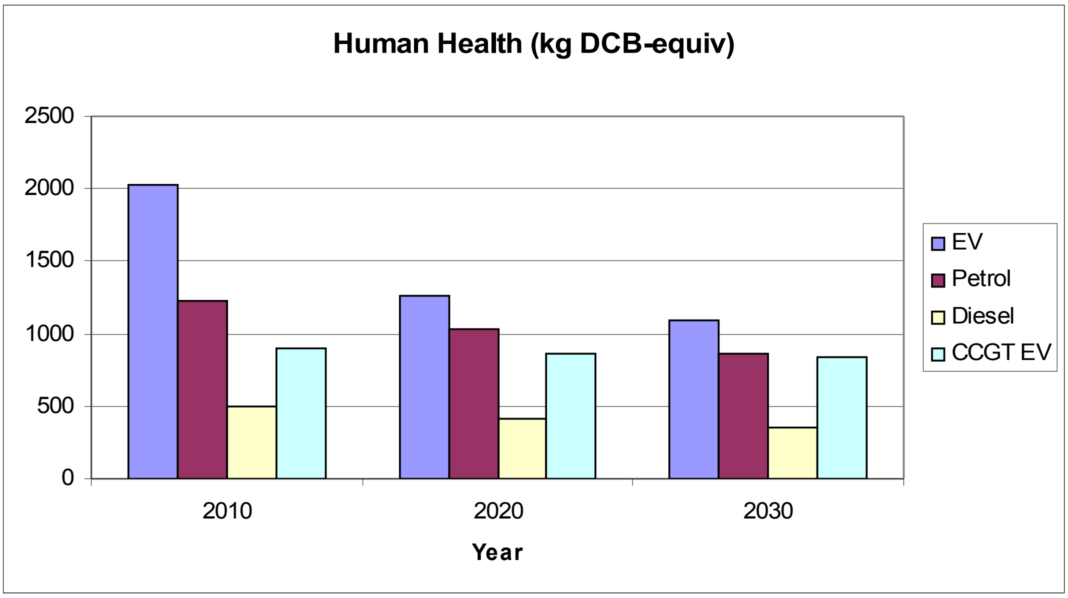
- The above chart does not include the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change
- The EV shows a marked reduction compared with ICVs, in terms of potential to cause eutrophication.
- The eutrophication potential is strongly related to the emissions of nitrogen oxides. In all scenarios for the EV, emissions of nitrogen oxides accounts for 97-98% of the 'use phase' impact.

3.5 Impacts to People

The impacts in this section are as follows:

- *Human Health* – the potential to cause adverse effects on humans; this is caused when a hazardous substance is taken into the body.
- *Noise* – the ambient noise made by the vehicle.

3.5.1 Human Health



- The above chart does not include the Defra marginal factor, as this is only provided for carbon dioxide emissions and is therefore only applicable to calculations for climate change.
- Most of the emissions that contribute to human health impacts are due to airborne heavy metals such as arsenic, vanadium and selenium. These primarily arise from use of coal. Another pathway occurs when heavy metals in water are consumed.
- The EV has a higher potential human health impact than the ICV. More than half of the EV emissions contributing to this impact (56%) occur in areas where resources are extracted to make the batteries. The remainder are associated with emissions as a result of supply and combustion of fuels (particularly coal) providing electricity to the National Grid arising from production of NO_x, SO_x and particulates during combustion of fossil fuels.
- The EV potential impact reduces over time, as the proportion of fossil fuels (particularly coal) supplying the National Grid reduces in line with Government policy.
- Whilst the EV results are higher than the ICV, they should be considered in the context of emissions associated with supply of electricity to the Grid in its entirety ie the additional requirement on the Grid to charge EVs has been estimated to be only 1% or less for the Business as Usual and Mid-Range scenarios.

3.5.2 Noise

EVs are inherently quieter than their petrol/diesel counterparts. A test documented in the Department for Transport's "*An examination of vehicle noise test procedures*" paper states that a diesel van produced noise levels of 75.6 and 71.4 dB(A) on two tests, while an equivalent electric van was quieter, producing levels of 68.8 and 68.2 dB(A) respectively. Bearing in mind that the decibel (dB(A)) scale is logarithmic these typical values indicate that under "both under average and extreme driving conditions the electric equivalent van has a distinct noise advantage". It worth noting that most noise in cars arises from tyre noise on the road and wind resistance, which will occur for the EV even if its motor is quieter, there is a potential of reducing traffic noise in urban environments.

Drivers of EVs will need to become accustomed to high speeds without significantly increased engine noise. Pedestrians and other road users will also need to become accustomed to quieter vehicles.

3.6 Review

The table below provides a summary of the analysis based on 2020 figures, based on findings in Sections 3.1 to 3.4. Further information on the methodology used and analysis are provided in Appendix A.

Summary of studied potential environmental impacts by vehicle type (assuming a Grid mix for 2020) for a single vehicle over vehicle life (180,000km)

Environmental Impact	EV	ICV[18]	Units	Context
Climate change	11,656	24,650	kg CO_2e	▪ The EV has less than half the impact of the ICV in 2020. ▪ The EV result is dependent on the proportion of renewables and nuclear supplying the National Grid, which will increase in line with Government policy.
Air acidification	56.2	44.8	kg SO_2 eq.	▪ ICV emissions occur at the tailpipe, potentially in more sensitive environments such as urban areas. By contrast, EV emissions occur at power stations supplying the Grid (particularly coal) which are generally in out-of-town locations. ▪ 23% of the EV impact occurs outside the UK due to extraction of materials for battery production; therefore the potential impact in the UK is comparable for the EV and ICV.
Photochemical oxidant formation	3.6	7.4	kg ethene eq.	▪ EV has about half the potential impact of the ICV. The ICV impact is mainly due to petrol, which has almost twice the impact of diesel due to emissions of carbon monoxide and non-methane VOCs. ▪ A proportion of the ICV emissions will occur in more sensitive environments, such as urban centres. EV emissions occur mainly at power stations in out-of-town locations.
Non-renewable resource depletion	76.9	161.0	Kg Sb eq.	▪ The EV impact is significantly less due to reliance on more abundant resources (coal and gas supplying the Grid) in comparison with oil supplying fuels for the ICV. ▪ EV impact will continue to decline with greater use of renewables supplying the Grid.
Water use	34,306	1,541	Litres	▪ The EV requires substantially more water consumption than the ICV. One-third of this water use is due to refining of lithium salts outside the UK. ▪ The remainder is due to water losses eg from cooling towers, at power stations

[18] ICV figure calculated as 50% petrol and 50% diesel, based on tables provided in Appendix A.

				supplying the Grid. This arises from the extra 1% or less of electricity required from the Grid to charge EVs, which is negligible in comparison with electricity generation to meet all other needs. ▪ EV in-use water demand equates to about 8% of an individual's potable water demand in the same period.
Waste generation[19]	57.6	0.7	kg	▪ 86% of EV waste generation arises from extraction of materials for the batteries, outside the UK. ▪ In-use waste generation for the EV comes from the nuclear contribution to the Grid. ▪ Over 99% of waste is overburden, which is material that is temporarily moved at mines. This is not reflected in these figures.
Aquatic Eco-toxicity (freshwater)	33.7	40.5	kg DCB eq.	▪ 79% of the EV impact arises from extraction of materials for the batteries, outside the UK. ▪ EV in-use impact is markedly lower than for the ICV (18%).
Eutrophication	2.7	5.7	kg PO_4 eq.	▪ EV impact is less than half that of the ICV. ▪ >80% of the EV impact is in the UK.
Human health	1261	721	kg DCB[20] eq.	▪ >50% of the EV impact is due to extraction of materials for the battery outside the UK. ▪ Emissions contributing to the human health impact for the EV in-use are roughly half the in-use impact of the ICV. ▪ Some ICV emissions occur at the tailpipe (43% combined) and may therefore be emitted in more sensitive environments eg urban areas. In-use EV emissions occur at power stations mainly located away from urban centres.
Noise	68.8-68.2	75.6-71.4	dB(A)	▪ Results are for a van – the EV provides a "distinct noise advantage". ▪ EV drivers will need to become accustomed to high speeds without significantly increased engine noise. Pedestrians and other road users will need to become accustomed to quieter vehicles.

[19] Without overburden (material temporarily set aside during mining operations)
[20] dichlorobenzene

4 Battery Technology

4.1 Summary

- The widespread roll out of EV and PHEV is dependent on advances in battery technology – principally improvements in cost, performance and safety.
- Although nickel metal hydride (NiMH) is currently the dominant battery chemistry for HEV applications, there is a consensus that lithium ion (Li-ion) offers the most promising combination of power and energy density for wider rollout of EV and PHEV.
- Batteries currently tend to be optimised for high energy, pure EV application or high power, HEV applications. PHEVs must operate as a mixture of the two, which is a challenge for currently-available batteries.
- Li-ion batteries sourced from recognised suppliers to the automotive sector, with cost ranging from $1,000 per kWh to $2,000 per kWh, are currently too expensive by at least a factor of two compared to that needed to fulfil the requirements of most pure EV deployment scenarios.
- The battery sector is confident that this relatively new technology will decrease in price in the medium-long term, based on the massive investments that manufacturers are making in this technology and the falls in the price of mass-manufactured cells for consumer applications. In the short term battery prices are unlikely to fall sufficiently quickly to make pure EVs economically competitive with conventionally-powered vehicles.
- The lack of a UK-based manufacturer of cells for automotive applications means that the most significant UK business opportunity in the battery field lies in battery pack and battery system development and manufacture.

4.2 Introduction

The widespread roll out of EV and PHEV is critically dependent on overcoming on-board energy storage barriers – principally issues of cost, performance and safety[21]. Although it is acknowledged that there are a number of possible available alternative energy stores available (for example, fuel cells and supercapacitors) the subsequent discussions will focus on batteries. The increasing focus on electrification of transport has provided an impetus to the development of batteries capable of meeting the performance requirements for EVs with evidence of considerable activity in the US, Asia and Europe.

4.3 Cost and Performance Requirements for EVs and PHEVs

The table below presents a recent summary prepared for the California Air Resources Board on the energy storage requirements for HEVs, PHEVs and EVs[22].

	Max. weight (kg)	Peak power (kW)	Power density (W/kg)	Minimum electric start capacity (kWh)	Energy density (Wh/kg)	Cost ($/kWh)
HEV	50	40-60	800-1,200	1.5-3.0	30-60	
PHEV	120	65; 50[23]	540; 400[23]	6;12[23]	50;75[23]	300

[21] Status and Prospects for Zero Emissions Vehicle Technology, F. R. Kalhammer et. al., CARB Report, April 2007.

[22] Data from Status and Prospects for Zero Emissions Vehicle Technology, F. R. Kalhammer et. al., CARB Report, April 2007.

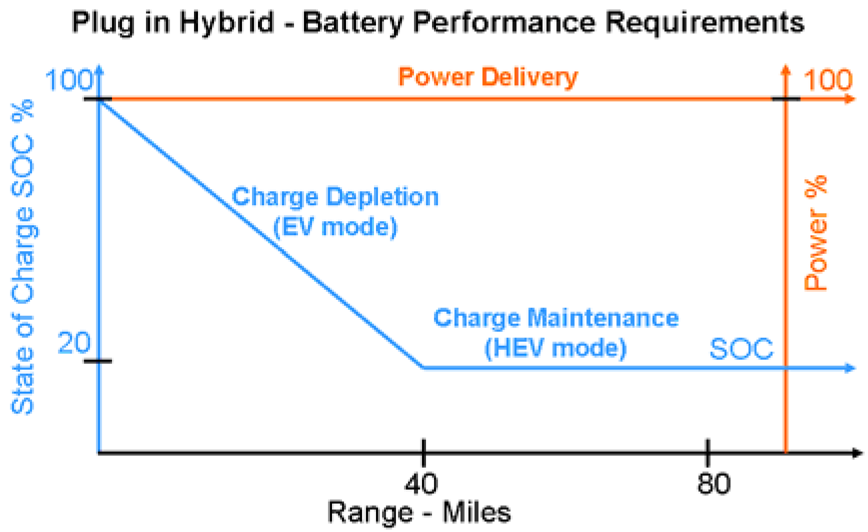
EV	250	50-100[24]	200;400[24]	25;40[24]	100;160[24]	150

The figures presented in the table are consistent with targets established by the United States Advanced Battery Consortium for vehicle batteries[25].

These performance targets arise from the different requirements of vehicles and have significant implications on the size and life of the battery. For EVs the battery must have the maximum energy density possible in order to provide the vehicle with acceptable range for a given battery weight and volume – the total energy contained in the battery is essentially comparable to the size of a vehicle fuel tank. EV batteries therefore are relatively heavy, and so their power density (comparable to the octane rating of a vehicle fuel) can be lower.

A HEV battery must have sufficient power to launch the vehicle, and be capable of providing high power at potentially very short intervals, but shallow depth of discharge (DoD) to the battery.

PHEV must operate as a mixture of EV and HEV – providing an electric-only range of a given number of miles and to a controlled, pre-determined depth of discharge (often 70-80%) in charge depletion mode. The battery then switches to HEV mode into cycles of high power, but repeated shallow discharge in charge maintenance mode. These requirements are summarised in the figure below[26].



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[23] For mid-sized PHEV with electric-only ranges of 20 and 40 miles respectively.

[24] For small and mid-sized EV respectively.

[25] USABC - Goals for Advanced Batteries for EVs http://www.uscar.org/guest/article_view.php?articles_id=85.

[26] N. Jackson, HEV and EV development: technical requirements for effective deployment, Advanced Battery Research in the UK, 13th March 2008, London.

4.4 Available Battery Technologies

The table below summarises comparative performance, price and safety issues for potential and actual vehicle batteries presented at a 2007 industry forum. A column for supercapacitors is included for comparison[27].

	Li-ion	**Li-M-Polymer**	**NiMH**	**$Na\text{-}NiCl_2$ (Zebra)**	**Lead-Acid**	**SC[28]**
Energy density (Wh/kg)	75-120	100-120	50-70	100-120	20-30	3-4
Power density (W/kg)	1,000-3,000	200-250	1,000-1,500	180	200-500	1,000-3,000
Cost ($/kWh)	1,000-2,000	?	1,000	600	100-200	15,000
Lifetime (cycles, 100% DoD[29])	1,000-3,000	?	2,000	1,000	300-800 (VRLA[30])	500k-1m
Issues	Safety, cost	No commercial product	Temperature limitations	Single supplier		Lifecycle issues

The figure below shows a view of the challenge provided by the energy storage capabilities of various technologies in relation to the requirements of EVs[31]. It illustrates that currently available batteries tend to be optimised either for high power (HEV) or high energy (EV) application.

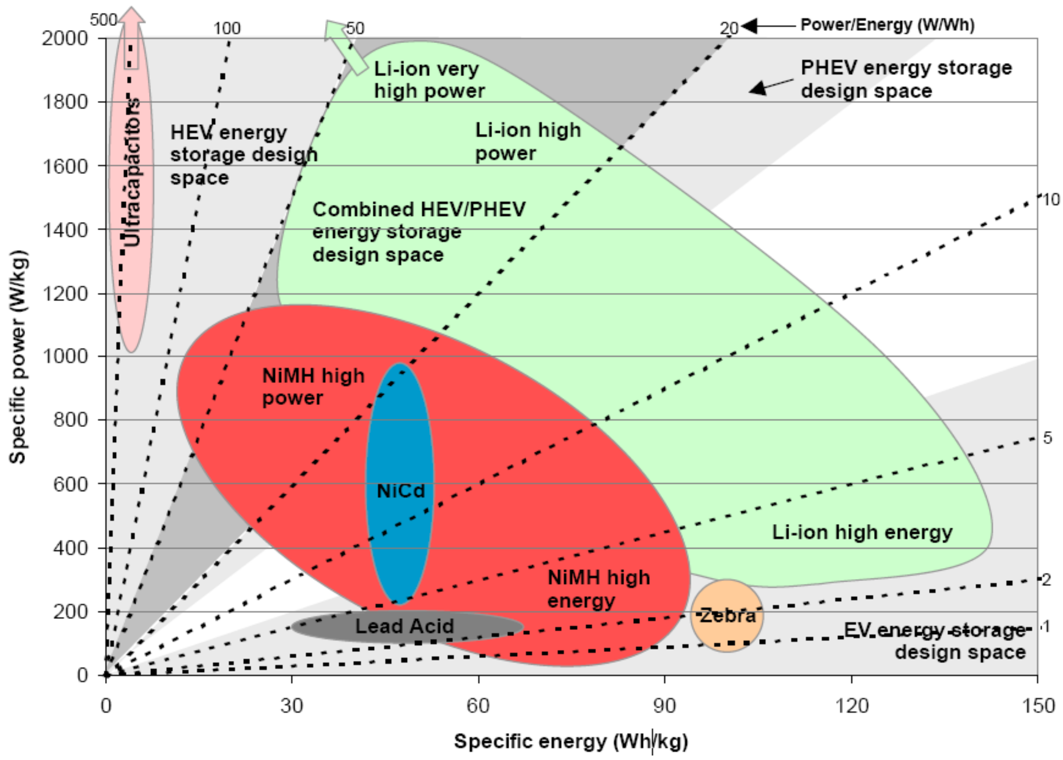
[27] Shanghai Challenge Bibendum, Round Table 2, Batteries and Supercapacitors, November 2007. Based on a 20kWh EV battery pack and a 100Wh supercapacitor. By comparison, the potential energy density of gasoline is around 12,000 Wh/kg, and that of hydrogen 33,000 Wh/kg.

[28] SC – supercapacitor.

[29] DoD – depth of discharge.

[30] VRLA – valve-regulated lead acid battery.

[31] Courtesy of Ricardo.



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Although NiMH batteries currently dominate the HEV market, with Toyota recently having exceeded 1m hybrid vehicle sales worldwide using this battery chemistry, there is a growing consensus that Li-ion batteries offer the most promising combination of energy storage capacity with power. While new models due to be launched in 2009 such as the next version of the Toyota Prius and a new Honda hybrid will still use NiMH, subsequent discussion will focus on Li-ion technology.

4.5 Lithium-ion Battery Technology – Introduction

Li-ion batteries have part of their origin in research in the UK. In the 1970s John Goodenough (now at University of Texas) was working in the Electrochemistry Laboratory at the University of Oxford, when he made crucial discoveries on Li ion conduction in $Li_{1-x}CoO_2$ and $Li_{1-x}NiO_2$ that led to a key patent on the use of these oxides as intercalating cathodes in batteries. The work was sponsored by the UKAEA at Harwell who were collaborators in the research. Their successor, AEA Technology PLC, held the right to license the technology in the 1990s and was later involved in the development of the Li-polymer battery with Sony and the construction of the AGM battery plant in Scotland[32]. It is instructive that Dr Goodenough struggled to find backing for the commercialisation of his technology in the West[33].

[32] J. Matthews, UK Advanced Battery Capabilities, UKTI Internal Report.

[33] Factors Affecting U.S. Production Decisions: Why are There No Volume Lithium-Ion Battery Manufacturers in the United States? R. J. Brodd, prepared for NIST, June 2005. http://www.atp.nist.gov/eao/wp05-01/wp05-01.pdf.

4.6 Lithium-ion Battery Technology – Cell Chemistry

Although there is not room for a detailed presentation of Li-ion battery chemistry, it is worth discussing briefly the different candidate battery chemistries that are available for this evolving technology before turning to price-performance trends[34].

Lithium is the lightest metal and most electropositive element, making it a very attractive battery cathode material. The table below presents data for lithium cathode battery chemistries that are considered as promising candidates for PHEV and EV applications[35].

Cathode chemistry[36]	Nominal voltage	Advantages	Disadvantages	Makers	Automotive application status
NCA	3.6	proven; energy density; power density	safety; cost	JCI/Saft; PEVE	Pilot
LMS	3.9	cost	lifetime; safety; low temperature performance	LG Chemical; Electrovaya	Development
LFP	3.3	safety; lifetime; DoD; cost	low temperature performance	A123	Pilot

4.7 Lithium-ion Battery Technology – Safety

The currently-prevalent nickel and cobalt-based oxide Li-ion cathode materials such as NCA have potential issues with overcharging. If such batteries are overcharged, metallic lithium is removed from the cathode and plates onto the anode which is then fully intercalated with lithium. This process also pushes the cathode to a higher voltage causing cathode decomposition, as well as electrolyte oxidation. These exothermic reactions can lead to the 'thermal runaway' (continued heat evolution even after the overcharging is ceased)[37]. Clearly, voltage control at cell, module and battery level is critical to prevent overcharging of automotive Li-ion batteries – all factors that will inevitably increase Li-ion battery cost relative to alternatives. Lithium iron phosphate cathodes offer a promising future alternative chemistry that avoids much of this problem and emerged during discussion with stakeholders as a promising near-term Li-ion chemistry for wider EV deployment.

The potential consequences of overcharging can be alleviated by electrode separators that melt at excessive temperatures to 'shut down' the cells, and improved formulations to minimise metallic lithium formation at the anode. Other new cathode and anode materials continue to be explored and developed which will further mitigate safety concerns.

[3434] For a more detailed analysis see Batteries for Electric Drive Vehicles – Status 2005, F. R. Kalhammer, EPRI 2005.

[35] Data derived from: Status and Prospects for Zero Emissions Vehicle Technology, F. R. Kalhammer et. al., CARB Report, April 2007; Electric Cars: Plugged In, R. Lache et. al., Deutsche Bank, 2008; Batteries for Plug-in Hybrid Electric Vehicles (PHEVs): Goals and the State of Technology circa 2008, J. Axsen et. al, ITS, University of California Davis, May 2008.

[36] NCA – lithium nickel cobalt aluminium. LMS – lithium manganese spinel. LFP – lithium iron phosphate.

[37] Nanophosphate Lithium-Ion Technology for Transportation Applications, A.C. Chu, presented at EVS-23, December 2007.

There has been adverse publicity in recent times concerning the safety of Li-ion batteries, particularly in personal electronic applications. It is important to stress that over 200 Li-ion equipped electric and hybrid vehicles were road tested in California, Europe and Japan from 2002 - 2007, with no reported significant safety problems[38].

4.8 Lithium-ion Battery Technology – Current and Projected Cost

It is clear from discussions with industry and from published sources that even minimum costs for high energy:power ratio EV and potential PHEV batteries presently exceed projections and targets by at least a factor of two[39].

The table below presents a summary of published present, projected and targeted cost targets for high energy EV batteries: the first section of the table gives actual price data from two recent sources; the second gives projections of costs based on the stated production volume scenarios; and the final section presents the USABC long-term target for battery cost at a production volume of 25,000 units per year.

Who[40]	**Price ($/kWh)**	**When**	**Comment**
		Recent price data	
EUROBAT (2005)	1,000-2,200	2005	€700-€1,500 (at €1=$1.48)
Challenge Bibendum Battery Round Table (2007)	1,000-2,000	2007	
		Future price projections	
EUROBAT (2005)	296	2020	€200/kWh (at €1=$1.48) target at end of 15 year research programme; 100k production volume/annum; 30kWh battery
ANL (2000)	250	Future	Optimistic projection based on future price of materials
IEA (2005)	270	Future	Data taken from EPRI 2003. Plus $800 balance of plant
EPRI (2005)	280	Future	100k production volume/annum; 30kWh battery
CARB (2007)	240-280	Future	100k production volume/annum; 25kWh battery
		Long-term target	
USABC	100	Long-term target	25k production volume/annum; 40kWh battery

There is clearly a gap between the long-term price projections and aspirations for high energy batteries and current prices. In discussions with industry, it was often noted that lead acid batteries continue to be developed and improved despite being a technology that has

[38] Status and Prospects for Zero Emissions Vehicle Technology, F. R. Kalhammer et. al., CARB Report, April 2007.

[39] Energy Storage Research and Development: 2007 Annual Progress Report, D. Howell, EERE, January 2008. http://www.transportation.anl.gov/pdfs/B/506.pdf.

[40] Data taken from: EUROBAT (2005) – Battery Systems for Electric Energy Storage Issues, July 2005; Shanghai Challenge Bibendum, Round Table 2, Batteries and Supercapacitors, November 2007; ANL (2000) – Costs of Lithium-Ion Batteries for Vehicles, L.Gaines et. al,, ANL, May 2000; IEA (2005) – Prospects for Hydrogen and Fuel Cells, D. Gielen et. al, IEA, 2005; EPRI (2005) – Batteries for Electric Drive Vehicles – Status 2005, M. Duvall et. al., EPRI, November 2005; CARB (2007) - Status and Prospects for Zero Emissions Vehicle Technology, F. R. Kalhammer et. al., CARB, April 2007; USABC - Goals for Advanced Batteries for EVs.

existed for well over 100 years. There is optimism that towards the end of the period covered by this study prices for Li-ion batteries will decrease towards the aspirational projections in the above table. However, in the nearer term there is less certainty that their price will fall significantly and are certainly unlikely to reach the sub-$300 levels shown in the table. In a presentation at the international Electric Vehicle Symposium at the end of 2007, the US National Renewable Energy Laboratory stated that “meeting cost, life and energy density targets for a 40-mile long-term” battery is expected to be “very challenging”[41].

Industry sources indicate that the best current UK price for a large EV battery pack is around $800/kWh using cells sourced from a company in China that is not allied to one of the major Asian cell manufacturers. Although the wider automotive industry has not shown any willingness to source cells that are not from established players in the battery field, there are clearly niche opportunities for players to offer battery packs if they are willing to provide guarantees to address customer concerns on the quality of cells sourced in this way[42].

4.9 Lithium-ion Battery Technology – Potential for Cost Reduction

The table in section 4.8 shows that the projections for Li-ion battery costs are critically dependent on production volumes. If Li-ion cell, module and battery costs are to fall over the next ten to twenty years, then it is important to understand where in the production process these cost savings can be realised. Two principal factors that could drive cost reductions in batteries are optimisation of manufacturing with increased production and the transition to alternative lower cost materials.

The trend of anticipated fall of production cost of Li-ion batteries with increased production volume mirrors the “experience curves” that are often cited for other advanced technologies such as fuel cells and photovoltaic systems[43]. The experience curve rationale states that an increase in production volume yields a predictable decrease in unit production costs, due to factors such as improvements in labour efficiency, standardisation of production and optimisations in the value chain. Applying this reasoning, it is often stated that the unit cost of production falls by around 20% for each doubling in production volume – for example, the unit price of photovoltaic systems in the US decreased five-fold between 1976 and 1992. However, the experience of photovoltaics also shows that projecting future cost reductions simply on the basis of experience curves is fraught with difficulties, as they cannot take account of local market interventions nor can they predict the effect of technological breakthroughs. Turning to batteries, the experience curve rationale mainly applies to cells, where there is room for optimisation of production through automation – providing quality can be maintained. The balance of the battery system (module and battery assembly) requires considerably manual intervention and is likely to follow different cost reduction paths. It is clear that considerable cost reductions for cells will ensue in mass production, based on the experience of the manufacture of cells for consumer applications.

The transition of automotive Li-ion batteries to mass production is just beginning. For example, GS Yuasa Corp., Mitsubishi Corp and Mitsubishi Motors Corp, recently announced the formation Lithium Energy Japan, a joint-venture aimed at manufacturing high-capacity Li-ion cells[44]. The company, which claims that it will the first mass manufacturer of large Li-ion EV batteries, is aiming to begin operation in 2009, targeting a production volume of 200,000 cells per year, sufficient to power 2,000 Mitsubishi i-MiEV EVs. Given that the

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[41] Battery Requirements for Plug-In Hybrid Electric Vehicles – Analysis and Rationale, Dr Ahmed Peseran, Presentation to EVS-23, December 2007.

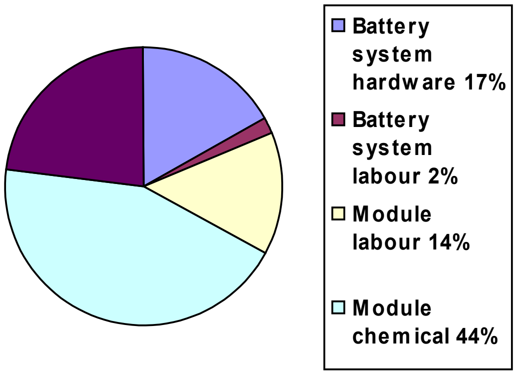
[42] Buying Batteries in China (Caveat Emptor), B. Lawson, Battery and Energy Storage Technology, January 2008.

[43] Experience Curves for Energy Technology Policy, C-O Wene, IEA, 2000.

[44] http://lithiumenergy.jp/en/pdf/20080806e.pdf

targets mentioned in the table in section 4.8 are for battery production volumes of at least 25,000 units per year, considerable increases in production volumes are needed before the cost-volume benefits anticipated in the table are realised.

Turning to materials, a 2005 study indicated that the breakdown of cost for a mass produced Li-ion battery is as follows[45]:



Materials required for the function of individual cells therefore account for approaching half of the cost of a battery. Industry sources have indicated that, to the nearest 5%, typical cell material costs in a lithium cobalt cylindrical cell break down as follows: cathode materials 35%; separator materials 30%; electrolyte 15%; anode 10%; casing 5% and other 5%.

The most significant element is the cost of a Li-ion cell is the cathode material. Li-ion batteries offer cost reduction potential above those of NiMH batteries: most sources indicate the nickel prices will continue to rise whereas, with the combination of increased production and eventual availability of new materials, the cost of the active materials in the Li-ion battery is expected to fall. This will become increasingly true as metals other than cobalt, such as manganese or iron, are used in the cathode. Research in this area is ongoing, as is research into polymer or gel electrolytes and new anode and separator materials. Each offers its own cost reduction potential that will become apparent in the longer term, but is unlikely to have a significant short-term impact.

4.10 Lithium-ion Battery Technology – Lifetime and Performance

Sizing of batteries for required application is important. For example, as battery cost does not scale proportionately to cell size (ie, in terms of energy output per unit cost, smaller batteries are relatively more expensive than larger ones) it is important for manufacturers to maximise power density while maintaining minimum energy capacity, particularly for PHEV capable-batteries. The first generation Toyota Prius battery was overspecified for this reason (Toyota has stated that the second-generation model battery introduced in 2004 is 15% smaller, 25% lighter, and has 35% more specific power than the first[46]) and it seems clear that the initial version of the GM Volt PHEV will have a battery that is more than capable of meeting its energy and power requirements in order to provide a range of operation that will extend the battery's life. The overspecification of the battery, and management of its range of operation, will improve its lifetime, but inevitably increases its cost.

According to a recent US analysis[47], a battery system with a rated capacity of 40kWh would provide a family-sized EV with a maximum driving range of 125 miles (assuming a power consumption of 250 Wh/mile). Significant breakthroughs both in energy density and in

[45] Batteries for Electric Drive Vehicles – Status 2005, M. Duvall et. al., EPRI, November 2005.

[46] http://pressroom.toyota.com/Releases/View?id=TYT2004062345528

[47] Status and Prospects for Zero Emissions Vehicle Technology, F. R. Kalhammer et. al., CARB Report, April 2007.

vehicle lightweighting are required before battery EVs are capable of range performance comparable to current ICVs.

4.11 Implications for the UK Battery Sector

The potential widespread deployment of PHEVs and EVs in the UK presents significant opportunities, but also raises a number of questions to the UK automotive sector. As well as the implication for the UK economy, the question arises whether it is desirable to replace foreign-sourced oil with batteries sourced from and manufactured abroad. It is not just the UK that is dealing with these questions – a 2005 report commissioned by the Advanced Technology Program of the US National Institute of Standards and Technology presented a picture that is familiar to analysts of UK high-technology sectors[48]. The analysis indicated that the US had successfully incubated new battery technologies, but investment for their volume manufacture and profitable exploitation occurred in Asia. Although the report was primarily aimed at small-scale cells for consumer electronic applications, findings highlighted in the study were:

- US companies have not pursued volume manufacturing in the US mainly because of the low short-term return on investment due to the time required for commercialisation
- Labour costs were not cited as significant
- Support was needed to establishing manufacturing

The study warned that there was a danger that cell research and development would inevitably follow manufacturing East as a consequence of the Asian economies' strengths in manufacturing and their ability to present a 'joined-up' cycle from research to deployment in a single geographic region.

The growing interest in Li-ion chemistry particularly for PHEVs in the US may revise this thinking. For example, EnerDel, part owned by Delphi, has a stated intention to produce its Li-ion HEV batteries in the US. As reasons for this approach, the company cites Delphi's connections with the automotive supply chain and the ability to exercise control over production quality by establishing highly-automated production processes (developed in Japan) with lithium titanate anode technology developed at Argonne National Laboratories[49].

Many leading automotive players have acted to secure their future battery supply chain for EVs by establishing joint ventures with cell and battery suppliers (for example, Volkswagen with Sanyo, Toyota with Matsushita and Nissan with NEC). The South Korean government has acted to coordinate the work of its domestic supply base: the Korean Ministry of Knowledge Economy and Korea Automotive Technology Institute will work with Hyundai, Samsung, LG Chem and SK Energy on a five-year, $1bn project to develop Li-Ion batteries for PHEVs[50]. Industry sources have indicated that in the absence of a major domestic manufacturer of secondary Li-ion cells for the automotive market, the design and integration of cells shipped from abroad into modules and battery packs offers the most promising opportunity for the UK automotive electronics sector. Companies such as Dundee-based Axeon Power offer capability that is leading edge not just in the UK but in Europe.

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48 Factors Affecting U.S. Production Decisions: Why are There No Volume Lithium-Ion Battery Manufacturers in the United States? R. J. Brodd, prepared for NIST, June 2005. http://www.atp.nist.gov/eao/wp05-01/wp05-01.pdf

49 http://enerdel.com/content/view/100/83

50 http://english.chosun.com/w21data/html/news/200808/200808250020.html

5 Charging Infrastructure

5.1 Summary

- Battery exchange would require a high level of vehicle standardisation. The development of charging infrastructure will need to keep pace with the developing market to ensure consumer confidence in the ability to recharge their vehicles with minimal inconvenience.
- There should be standardisation of recharging systems to maximise commonality and minimise development of manufacturer specific systems.
- On street charging will be necessary to encourage EV and PHEV uptake and regulated asset status for charging points would aid their deployment.

5.2 Discussion

There are a number of technologies for charging batteries which vehicle manufacturers and utility suppliers should discuss to achieve a level of standardisation for EVs. In general they fall into the categories: slow charge; fast charge; and conductive, inductive.

Slow and fast charging has been discussed elsewhere in this study. The essential difference between conductive and inductive charging to the consumer is that conductive charging requires a connection *via* a plug like many household appliances, whereas inductive charging requires no direct plugged connection, only proximity. A common inductive connection is an electric toothbrush.

Currently charging points in London are conductive and suit the current vehicles available. Vehicle manufacturers and the utility companies need to discuss and agree a common preferred system for the future.

5.3 Home Charging

The most common location for charging an electric car will be at home utilising a 240V/13A or 16A connection. This will require a switchable socket and a surge protection device, but should not pose any problems for most UK homes.

5.4 Public Charging Points

For practical and peace of mind reasons the abundance of public charging points will be important. The points currently installed in London are conductive 240V/13A similar to the domestic supply. These can accommodate trickle charging, but not fast charging. There are a number of potential methods for charging for their use including an annual fee with free access or charging by the unit of time used. These chargers will need to be deployed both on streets and in car parks. Other areas of consideration are charging access for blocks of flats and work based charging.

Charging points, like water and power distribution networks and telecommunications networks, could be designated as regulated assets, typically enabling the service provider to cover installation and operating costs and achieve an adequate return on their investment. This could be an incentive for utility firms to install them.

5.5 Commercial Vehicle – Depot Charging

It could be useful for the efficient operation of commercial vehicles to have access to three phase power for charging their high capacity batteries. The operational requirement for maximum usage of a vehicle will benefit from quick charge during a planned operational break such as reloading or driver lunch break. These connections should be available at most industrial or light commercial sites.

5.6 Fast Charging Stations

Fast charging requires more complex chargers than currently deployed on the London streets. These chargers will be designed such that they can detect battery cell chemistries to prevent damage due to an inappropriate charging profile. The problems of supply attendant with fast charging are discussed in sections 6 and 8; these problems could be overcome by the siting of a substation close to any fast charging station, or by local energy storage at the station. With the initial growth of EVs in city areas, well distributed fast charging stations will afford a high degree of security for nervous potential users. For EVs to expand outside city areas these stations are essential.

5.7 Battery Exchange

A limitation of the EV as it currently exists is that imposed by the battery's capacity and the time to recharge it. A battery exchange system is sometimes proposed as a solution to this; swapping a depleted battery for a fully charged one at an "electric filling station".

Countries with relatively low vehicle numbers and standardised battery type or low numbers of variation are an example where battery exchange may work well. This model has been proposed for both Denmark and Israel and is part of the Project Better Place introduction strategy, which is supported by Renault/Nissan.

That said there are a number of significant issues which will need to be overcome:

- The battery pack for an average passenger car will weigh 250 to 300kg. To provide good weight distribution and thus safe handling of the car, the battery pack could be specifically designed for that vehicle and therefore integrated into the structure. If this were the case then to change the battery pack will be far more time consuming and difficult than those we are used to in our current ICVs, and will require specialised handling equipment.
- From a safety perspective, the electrical connection between the battery and the vehicle carries a very high current, and it is this connection that would need to be made and broken each time the battery is exchanged. At best, it will cause wear and degradation at the key link between the two components, at worst, it has the potential to cause a massive discharge, with all the consequences that might ensue.
- As stated above, the battery pack shape and the electrical architecture is likely to be unique to each vehicle, unless standards were introduced; so every exchange station would have to carry a considerable stock of fully charged batteries even to support the most popular vehicle models. This would entail considerable financial outlay, which would have to be paid for by the end user.
- The UK contains many areas of considerable traffic density and numerous vehicle types. For such a scheme to operate would require a diverse stock of batteries.

Also, battery technology already exists to provide a small sports car with a range of 200 miles on a single charge, and the potential speed of battery development is such that this figure may possibly increase to a point where battery exchange is not required for relatively long journeys in a large passenger car. In addition, with the ability to fast charge batteries (eg in 10-30 minutes) the need for battery exchange may not arise.

Overall, battery exchange may have a role in the early introduction of EVs and if high levels of standardisation are achieved then could be viable in the longer term, dependant on the development and deployment of charging technologies. It would require the cooperation of EV manufacturers and importers at an early stage to influence battery pack design to enable exchange systems to be widespread.

6 Electricity Generation and Grid Impacts

6.1 Summary

- The impact of EVs and PHEVs on the UK electricity grid has been examined and there is sufficient generating capacity to cope with the uptake assuming that demand for charging is managed and targeted at off-peak periods where there is currently surplus capacity. This could be achieved through variable electricity tariffs related to grid demand.
- The development of smart metering systems which are able to automatically select charging times and tariffs to suit both the consumer and generating sectors will aid the management of load on the grid.
- The existing national transmission network will be sufficient to cope with the demand from vehicles. However, there may possibly be distribution issues where local networks are already close to capacity. In such circumstances this can be overcome with local reinforcement. Pilot studies will be required to assess the magnitude of these effects.
- There is potentially significant energy storage capacity within the EVs and PHEVs although there are a number of issues with regard to access and utilisation which requires further investigation.

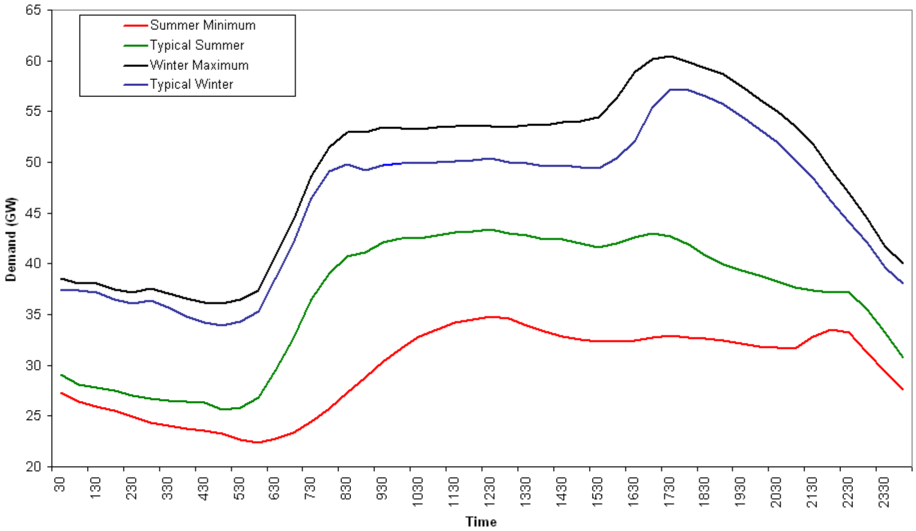
6.2 Operation of the Grid System

Before considering the grid impacts of EV charging, it is useful to consider how the grid operates and the variations in national electricity demand that currently occur.

The Electricity Industry in the UK has three key stakeholder areas. They are:

- **Generators** – responsible for generating the energy
- **Distribution Network Operators** – owners and operators of the network of towers and cables that deliver electricity to end users
- **Suppliers** – companies who supply and sell electricity to consumers.

Electricity demand varies from hour to hour and from season to season. Peak demands of the year typically occur on a workday evening in December or January at around 17.30, whilst the peak demand on a Sunday in summer would be around half the winter peak. Demand declines rapidly during the evening and then at a slower rate between midnight and 6am, before steeply increasing over the next two hours.



The prices in the wholesale electricity market vary by the half hour to reflect the varying cost of generation, incentivising extra generation at peak and encouraging more demand overnight. Most domestic customers currently pay for their electricity on a standard tariff rate that does not vary during the day, although some domestic and smaller commercial customers have dual rate tariffs. During winter, the lower overnight tariff incentives increase demand chiefly by switching on storage heating and water heating equipment (via time-switch and radio tele-switch). In summer this effect is reduced as only water heating contributes. These customers pay slightly more for their electricity during the day.

These dual rate tariffs were introduced in the 1960s to reflect the changing generation mix. Nuclear generation was less able to vary its output to match consumer demand and therefore greater load changes and start-ups were imposed on coal fired generation. To minimise the associated extra costs, “white meter” tariffs sought to flatten the daily load profile.

Wholesale markets, as reflected in the balancing market, currently exhibit variations in price from £40 to £120 per MWh. Domestic retail tariffs, such as Economy 7 which offer different rates for day and night also exhibit significant price differentials. For example EDF Energy day rates for the London area in September 2008 were over 13p/kWh excluding VAT (20.79 p/kWh for the first 1000 kWh per year and then 12.47 p/kWh), but only 4.98 p/kWh excluding VAT overnight. For comparison, standard EDF Energy electricity tariff rates are over 16p/kWh. Such price differentials could provide a significant incentive to charge EVs during periods of lower prices.

In future, as renewables make a greater contribution more advanced tariffs or dynamic pricing may be used to encourage demand when generation is available. This may also help National Grid to balance generation with demand. To deliver dynamic pricing smart metering will be required and the development of such systems could be extended to naturally encompass charging of EVs and PHEVs.

Vehicle charging has the potential to place a significant burden on the grid unless it is managed by smart metering. This will help the distribution network to balance the system more effectively and provide the consumer with the most cost effective energy.

There is also a corresponding difference in carbon emissions per unit of electricity generated between peak and off peak (eg day and night). This is partly due to lower carbon sources (eg nuclear and hydro) forming a greater part of the overnight mix, whereas at peak demands, relatively expensive and inefficient generation is called into service. Ignoring this mix argument, even if EV charging allows a partly loaded CCGT unit to approach full load, the efficiency gain might be of the order of 5% (52% part load efficiency to 57% full load efficiency), with corresponding reductions in carbon emissions per unit. There is the added bonus that lower overnight temperatures also improve the generation efficiency.

The chart below is a summary of the change in profile of total generation output between 2007 and 2030 to cover a demand of 380TWh by 2030.

Note: this BERR scenario – extended RO32% (excl. Severn Barrage) – does not predict significant growth in renewable energy production post 2020.

Output, TWh	2007	share 2007	2020	share 2020	2030	share 2030
Renewables	20.15	5%	112.42	32%	125.84	32%
Nuclear	57.25	15%	22.75	6%	51.04	13%
Gas	161.72	43%	146.94	41%	148.38	38%
Coal	129.00	34%	62.83	17%	48.97	13%
Oil	3.26	1%	0.00	0%	0.00	0%
Other	8.99	2%	15.11	4%	15.57	4%
Total	**380**	**100%**	**360**	**100%**	**390**	**100%**

6.3 Connection to Electricity Distribution Network

An issue of relevance to EV charging, and possible “vehicle to grid” (V2G) connectivity is the connection between individual homes or remote/bespoke charging points and the main transmission system. This connection is via the electricity distribution networks connecting homes at 230V ac (single phase).

If a significant degree of EV charging were undertaken during the early evening, for example if clusters of EV owners chose to start re-charging their vehicle batteries when they returned from work, the current diversity assumptions for local distribution may no longer be valid, potentially requiring significant investments in the capacity of the local network. If charging were concentrated in periods when demand would otherwise be lower, this effect on the local distribution network would be reduced. Such charging would also tend to increase the number of units of electricity sold without increasing the fixed cost of the networks and, because network charges are recovered on a per kWh basis, this could marginally reduce the network charges to other users. Distribution network charges currently make up nearly 20% of a typical consumer’s electricity bill.

6.4 Grid Impact

The study has utilised the four scenarios of vehicle numbers to understand the potential magnitude of energy required over time and the potential storage available for V2G schemes. The authors have discussed these scenarios with the major energy suppliers in the UK to understand their concerns and identify opportunities.

The calculation for total demand is as follows:-

Vehicle efficiency (kWh/km) x distance per year per vehicle (km/yr) = energy per year per vehicle

Number of vehicles x energy per year = total demand.

PHEVs are treated as 50% electric and 50% petrol/diesel.

Throughout this study the vehicle efficiency has been set as follows:-

0.16kWh/km for 2010

0.13kWh/km for 2020

0.11kWh/km for 2030

Improvements in efficiency over time reflect advances in battery and motor efficiencies, energy recovery and vehicle lightweighting.

Average annual vehicle distance travelled is [51]

18,475km for 2010

19,819km for 2020

21,331km for 2030

[51] DfT Road Transport Forecasts for England 2007

The projected total demand from all vehicles with the ability to connect to the grid is shown in the following chart.

	2010		2020		2030	
Generating capacity	79.9 GW		100GW		120GW	
Projected annual UK demand	380TWh		360TWh		390TWh	
Vehicle demand	GWh	% of NEP	GWh	% of NEP	GWh	% of NEP
BaU Range	10	0.003	400	0.1	4200	1.1
Mid-Range	13	0.003	1,800	0.5	6,700	1.7
High-Range	13	0.003	3,500	1.0	17,000	4.4
Extreme Range	13	0.003	7,400	2.0	31,000	7.9

NEP = GB National Electricity Production (UK less NI)

6.5 Electricity Demand – discussion

A study by the Oak Ridge National Laboratory, entitled Impact of Plug-in Vehicles on the Electric Grid (October 2006) stated the following. “A key question is: when would consumers recharge in their vehicles?” The optimum time for electricity providers is typically at night when demand is low and low-cost plants are the marginal providers. Any additional generation would come from these low-cost plants and not strain the existing Transmission and Distribution (T&D) system. However, for consumers the preferred time (without any incentives to change their preference) is likely to be as soon as they are within easy access of a plug. This is both most convenient since they are at the vehicle already, and also improves their options since they may need the vehicle soon and would prefer a more fully charged battery. Charging cars in off-peak periods, particularly at night (or when wind/renewable output is high) is an efficient use of the generating sector, and by flattening the daily demand profile this will improve generation efficiency. Whilst this generation efficiency improvement would not fully offset the additional CO_2 emissions associated with the extra energy, the marginal CO_2 increase would be less than the CO_2/MWh figures currently assumed by Defra. Day or peak charging is less desirable.

The daily journey profile and the evening peak generation period are closely aligned as shown in the diagrams in Appendix E and as such this could lead to a significant load on the grid, co-incident with the peak demand period if this situation is not managed. Their growth should ideally be matched with incentives to encourage “grid-friendly” charging profiles. The introduction of dynamic domestic electricity pricing (enabled via smart metering) would assist, and such changes may arise regardless of EVs as networks evolve towards “smartgrids”.

The growth of electric cars is likely to occur in city centres first, where distribution systems may require reinforcement if clusters of electric cars connect simultaneously to the grid. Pilot studies will be required to assess the potential effects on local distribution in these areas. If significant upgrading of the distribution network were required it might increase the cost of electricity delivered to the consumer. Since network charges relate to maximum demand (which would not be affected by off-peak charging) and kWh, ostensibly the total unit cost to consumers may reduce slightly as the relatively fixed network costs are divided by a greater number of total units. Only if this were not the case might this be unpopular and act against the uptake of electric cars.

With the growth of electric cars comes the problem of standardisation of infrastructure. The new cars will probably carry the charger on the vehicle, allowing them to plug in anywhere that is available. The IEC working group TC69 are currently working on refreshing the international standards that cover conductive recharging. Cars of this type only require a household plug connection (13 or 16 amp) to charge. Larger commercial vehicles would prefer to have three phase (65 amp) charging to ensure a quick turnaround of delivery vehicles; this is widely available on commercial premises but not elsewhere. Building in quick charge capability to a vehicle will however add further costs. Typically quick charge could take a battery from 20% to 80% capacity in 10 to 15 minutes but with potentially significant impacts on the generation and transmission/distribution networks.

In order for users of EVs to feel confident about purchasing vehicles and undertaking journeys, they will need reassurance that sufficient street parking/charging is available. Given the average journey length of 13.6kms and that 93% of journeys are shorter than 40kms, many cars will only occasionally use charging points away from their homes but, in order to have confidence in the vehicles, it may be important that public points are widely available. Recharging demand is likely to be higher in winter when heaters and lights are used more often. It should be recognised that charging at parking bays is more likely to be during the day and therefore electricity charges would be greater. This would be an incentive for most to only charge back at home overnight, however, in areas of high density housing there is minimal dedicated parking and overnight charging will pose a significant problem. If this has to be done at a parking bay it could be a major disincentive.

6.6 Vehicle Storage Capacity

There has been considerable discussion of the merits of using EVs and PHEVs as a distributed source connected to the grid. It is envisaged that this could provide help load levelling at times of high demand and provide storage of energy from renewable sources. The maximum storage capacity for the four scenarios is shown in the table below. It is shown as GWh and as hours of grid demand to provide a comparison:

	2010		2020		2030	
Storage Capacity	**GWh**	**Hours**	**GWh**	**Hours**	**GWh**	**Hours**
BaU Range	0.068	0.002	6	0.1	79	1.8
Mid-Range	0.089	0.002	29	0.7	151	3.4
High-Range	0.089	0.002	59	1.4	364	8.2
Extreme Range	0.089	0.002	124	3.0	653	14.7

Note: the conversion efficiency of the battery is 0.93 and 80% of its capacity is available.

However, harnessing and utilising this energy in a reliable form raises a number of issues which will need to be resolved. Whilst smart metering may provide a method of controlling supply to and from the grid, the rate of energy transfer will be determined by the connection between the vehicle and the grid. The amount of energy available at any one time will depend on the number of vehicles connected to the grid and the state of charge in their batteries. The energy providers will need to be fully confident of the availability and consistent reliability of the V2G energy, and the vehicle users will want to be confident of having a fully charged battery when they need it.

Smart metering would also need to encompass dynamic pricing to make export of electricity to the grid more attractive during periods when wholesale prices are high.

Concerns also exist that the increased cycling of the batteries in this application will adversely affect the life of the battery.

An alternative perspective on this scenario is “Vehicle to House” (V2H) – linking the car to house rather than the grid. This potentially provides three benefits: it obviates the issue of exporting energy back to the grid; can reduce demands on the grid as a supplementary supply to the house; and could also provide emergency backup in the event of power outages.

It can be seen that there are many unresolved issues in connecting EVs and PHEVs either to the grid or house and further investigations and pilot studies should be undertaken to assess the possible benefits and problems.

6.7 Energy Costs

EVs and PHEVs not only benefit from the lower carbon content of their energy as has been discussed elsewhere in this report, but they also benefit from the lower cost of electricity compared to fossil fuels.

The energy cost of fuelling an EV using off peak electricity is approximately one seventh the cost of fuelling a comparable ICV. However, there is a view that to allow fair comparisons the cost of battery depreciation should be included as part of the running costs of an EV.

The diagram below illustrates these comparative running costs and how they change over time, based on the following assumptions.

EV

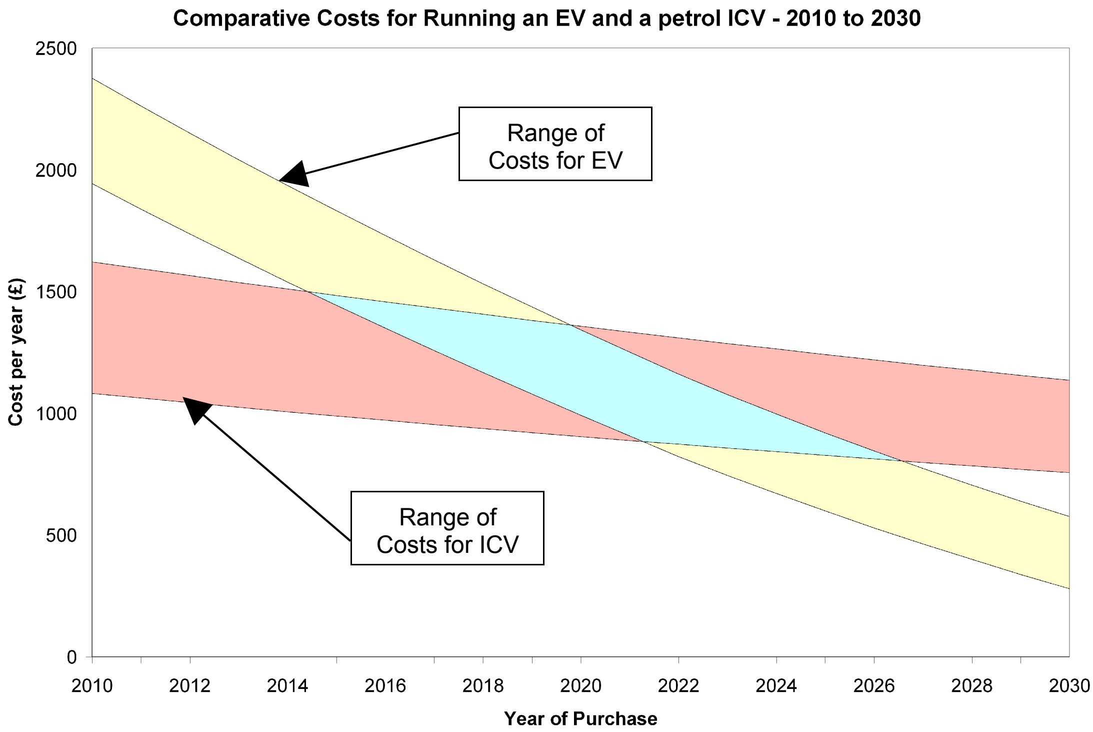
- The EV is assumed to have an efficiency of 0.16kWh/km in 2010, 0.13kWh/km in 2020, and 0.11kWh/km in 2030.
- The EV has a 35kWh battery which is assumed to cost £18,000 in 2010, £8,750 in 2020, and £1,800 in 2030. The battery is amortised over its assumed ten year life to give an annual cost.
- The curves for the EV show the difference in costs caused by charging at tariffs ranging from 5p/kWh to 20p/kWh. The 5p/kWh represents a low night-time charging rate. The 20p/kWh rate represents a peak day-time charging rate. Current electricity rates are around 15p/kWh during the day and 6p/kWh at night.

ICV

- The ICV is assumed to have an efficiency of 0.060l/km in 2010, which improves by 1.8% per annum to 0.050l/km in 2020, and 0.042l/km in 2030.
- The curves for the ICV show the difference in costs caused by refuelling at petrol pump prices ranging from £1.00/litre to £1.50/litre.

General

- Both vehicles travel 18,000 km a year.
- All other aspects of the EV and ICV are similar.



Within this scenario, although initially higher, with battery costs reducing over time EV running costs will fall significantly to levels below ICVs.

The overlap area shows when running costs for an EV would be competitive with an ICV powered car. This could be anywhere between 2015 and 2026 dependent upon the relative price to consumers of batteries, electricity and fossil fuels.

- With a petrol price of £1.10/litre and day-time electricity price of 15p/kWh. The crossover date is 2023.
- If the EV is charged at a night-time price of 6p/kWh, the crossover date is 2020.

The crossover date can be affected to occur earlier by relatively modest measures that differentiate between the two vehicles. For example, a £200 per annum differential brings forward the crossover date by approximately two years.

7 UK Business Opportunities

7.1 Summary

- The UK's automotive sector has a global reputation for research and development, design engineering and manufacturing. The development of EV and PHEV technology provides an opportunity for the UK to take a lead in the development and deployment of the new technologies required.
- There is a consensus among the organisations contacted that the trend is toward the electrification of the automobile. There remains uncertainty as to the timings, the technologies and the system designs, which could include diesel electric hybrids, fuel cells, EVs and PHEVs.
- The growth of UK manufactured EVs and PHEVs is likely to begin with the niche vehicle manufacturers already active in this field and then followed over time by the volume manufacturers.
- Opportunities for UK businesses exist in the development of batteries, internal combustion engines for hybrids, electric motors, control systems, energy recovery systems and battery recycling to meet the needs of this developing market.
- There is a strong sentiment in the vehicle manufacturing community that interventions by Government should be technology neutral.
- The ICE will continue to be used over the period of this study. Much of its on-going development will be undertaken by UK engineering companies.
- Inaction risks the future prosperity of the UK automotive sector as development and manufacturing moves to more sympathetic markets. It also potentially delays the CO_2 benefits derived from the widespread introduction of EVs.

7.2 Overview

The UK is the second largest passenger car market in Europe.

The UK supports a very successful automotive manufacturing industry, employing 194,000 people and contributing an annual £9.6bn of added value to the country's economy[52]. Vehicle production in 2007 was in excess of 1.75 million units, of which 77% of the cars and 61% of the commercial vehicles were exported. This production figure was an increase of 6% over 2006, despite the closure of the Peugeot plant in Ryton. The industry remains a significant part of the country's manufacturing, accounting for 6.3% of manufacturing value-added and 13% of total UK manufacturing exports.

Over a quarter of the industry is based in the West Midlands. There are also a significant number of companies in most other English regions and in Wales. Of this total, some 79,000 people are employed in vehicle and engine manufacturing, contributing nearly £5bn of added value to the UK economy.

Modern platform technologies support low volume variants rather than completely distinct models, and consequently automotive manufacturing has become more fragmented. Major OEMs are now able to manufacture in volumes as low as 5,000-10,000 units per annum, and smaller manufacturers have shown that even lower volumes can be viable.

For many years one of the obstacles to new vehicle manufacture has been the cost of making or buying-in a powertrain (engine and transmission). For EVs this is much less of an issue – batteries, motors and control units are all produced by Tier One suppliers, with few, if any constraints on who they can sell to. This immediately removes the investment

[52] ONS ABI 2006 data, November 2007, revised June 2008

necessary to design, develop and manufacture ICEs, which can only be done economically in medium to high volume.

This availability of "off the shelf" equipment will enable start-ups/niche manufacturers to compete on more even terms with existing VMs, purchasing the same products from the same suppliers, and thereby having the same development and warranty support. The manufacturer will then create its own identity by building the driveline into its own design of body and interior. The manufacture of these can also be readily outsourced (and frequently is), enabling the EV company to be an integrator – sourcing and assembling the major assemblies, but not owning the machinery to produce them. This will help new companies to develop new EVs without the high level of investment normally necessary to put a vehicle into production.

7.3 Existing UK EV & PHEV Expertise

7.3.1 Capabilities

The EV industry in the UK is a growing community, with companies offering capabilities to deliver vehicle technology from a single battery pack to a whole vehicle. Broadly speaking the UK EV industry has capabilities in energy storage, design engineering, and vehicle design and manufacture. In common with the wider UK motor industry, the UK EV industry offers significant strength in the design engineering area.

7.3.2 Energy Storage

The UK has a strong research capability with significant clusters of capability and new industry in Scotland, Yorkshire, and South East of England. This reflects a sound scientific base focused on conducting polymers and ceramic materials. A handful of companies are involved in understanding the provision of electrical energy storage for automotive drive, most notably Axeon Power. Whilst this market should expect to expand with an increase in EV sales, it is clear from discussions with the industry that core battery cell manufacturers are unlikely to relocate from the current production locations (mostly the Far East). Therefore, a developed UK capability would focus on the technical effort required to take battery cells or supercapacitors into battery packs with functional battery management systems ready for vehicle integration.

7.3.3 Design Engineering

A strength area in the UK automotive industry, design engineering is also a focus in the UK EV industry. Organisations such as Zytek, Lotus and Ricardo have proven histories in the development of systems for electric and hybrid EVs. Focused on the early development stages, these companies also gain from knowledge transfer through collaborative work with leading UK universities to develop new technology solutions.

A few of these design engineering companies are capable of producing vehicles, where volumes start at single prototypes and can go up to small series. These types of project typically incorporate new technology into an existing carrier vehicle, as demonstrated by the smart EV, which contains electric drive systems developed and installed by Zytek. Additionally these businesses have the capability to produce bespoke components for these vehicles, such as motors or controllers. However, in occupying the design engineering space in the supply chain, it is unlikely that these companies would directly undertake the volume production either of systems or of components. More probable is the development of technology solutions for other volume manufacturers, or licensing third party manufacture.

Transferable skills from traditional internal combustion engine design and development have helped provide this foundation in the UK EV industry. For example, engine control unit and gearboxes development skills are similar across the vehicle space.

7.3.4 Vehicle Manufacture

Several low volume manufacturers or assemblers are present in the UK; most prominent are Allied Vehicles, Modec and Smith Electric Vehicles in the light commercial vehicle sector. The UK is also host to companies manufacturing cars and public transport vehicles. With all these businesses the boundaries between manufacture and assembly vary depending on the method of operation. Some organisations manufacture the chassis and running gear and others utilise a rolling chassis/body from an external supplier (typically an automotive OEM). The common themes are the fitting of an electric drive system and an energy storage device (typically a battery pack).

The EV manufacturing environment differs from traditional vehicle manufacture, where OEMs typically also manufacturer the whole powertrain (engine and gearbox). An EV manufacturer can act more as an assembler, potentially accessing the majority of the powertrain and energy storage components as externally supplied parts.

Imported Vehicles

UK has a number of organisations importing complete EVs into the UK for sale. Whilst these organisations have no direct input to the UK EV supply chain (imported vehicles are typically manufactured in the EU or India), a considerable wealth of knowledge about the in-service capabilities of EVs resides within these organisations.

7.4 UK Business Opportunities

The authors have consulted with a variety of interested parties to ascertain the industry view of the risks and opportunities connected to the mass uptake of electric cars. The findings have in general been positive and optimistic that new opportunities can be created from this.

The findings can be summarised as follows.

- Increased electrification of transport is predicted. The technology for this is still in its infancy, and will evolve rapidly over the next 20 years. The UK is home to a large resource of R&D capability in its universities, the automotive and motorsport engineering sectors, and in electronics, aerospace, civil engineering and defence industries. There is a need to bring together the collective skills to focus on the next generation of EV technology and the infrastructure it requires.
- This in itself will encourage the supply industry to undertake research in the UK, and will bring work and added value from abroad to our universities and engineering companies.
- As a first step, technology around the world should be benchmarked to identify and quantify gaps and opportunities.
- There is insufficient battery manufacturing capacity around the world, and a number of the bigger automotive companies have established strategic alliances with battery manufacturers to safeguard their supplies and accelerate production. Li-Ion chemistry was originally developed in the UK, and there is a key role to play in the ongoing advancement of the technology. It is unlikely that volume manufacture of cells would be viable here, but there are opportunities for battery assembly, motor development and manufacture, and control systems algorithms and technology.
- The UK automotive industry leads the world in specialist manufacture, and as has been stated earlier, EV power facilitates and encourages niche low volume production. A number of small companies are already active in this field; with support and encouragement they can start to build the UK's EV industry.
- The UK automotive industry comprises a complex supply chain of small, medium and large suppliers, culminating at the VM with final assembly of the complete vehicle. The introduction of EVs and PHEVs into the UK market will primarily be substitution rather than additional. Therefore if the manufacture of these vehicles does not take place in the UK, total vehicle manufacture in the UK will be reduced from today's volumes. Some of the VMs that currently manufacture in the UK consider that the volumes they build here are marginal; a reduction on these volumes could change the business case and lead to a complete model range being moved overseas. This will impact not only the immediate workforce, but also the whole automotive supply chain.

- HEV products will become more widespread after 2010, with PHEVs being introduced by VMs in 2014/5. The introduction of PHEVs will dramatically reduce demand for HEVs. Also in 2014, pure EVs will start to come to market in volume, initially as small commuter vehicles.
- In the timescale of this study it is likely that electric power will emerge as a solution for vehicles operating over predetermined duty cycles of less than 150km. ICEs, using liquid fuels and possibly hydrogen in the future, will continue to be used in higher power demand applications – freight and (hybrid) premium passenger cars. The UK automotive industry has significant interests in ICEs, both in design and research, and in manufacture. The UK currently manufactures over three million ICEs per annum.
- Legislation has been a key driver in the development of low emission technology. Many of the manufacturers consulted for this study have indicated a preference that any Government intervention should be based on emission levels and should not proscribe technology. Legislation should be EU wide, and provide long term visibility to lead the progress of development and ensure that industry has time to develop satisfactory solutions.
- Local delivery vehicles and minibuses have duty cycles that comprise frequent stop/start operation. This is ideally suited to EV operation. Manufactured in very low volumes, the investment for these vehicles is small by comparison with the major VMs, but all of the companies in this market struggle to finance product development and to source components economically. Demand in this market currently exceeds supply, and with encouragement, this sector has the potential to grow significantly and is an ideal first niche for wider EV adoption.
- EV battery charging, will of necessity, take place at a number of disparate locations – home, work, public car parks, on-street. To optimise energy draw from the grid and enable the vehicle user to select the most cost efficient charging, smart metering will need to widely available. This will enable the network to predict off peak requirements and to recognise and bill individual users. Charging points are, as yet in a very early stage of their development, and there are very few companies producing them. They will not only need to be designed and manufactured in high volume, but they will also need to be installed, networked and maintained. This has the potential to become a core UK capability which could be exported.
- EVs will be manufactured and marketed not only by the traditional vehicle companies but also by entrepreneurs from other industries (eg Elon Musk with Tesla, Shai Agassi and Project Better Place). These new companies, unencumbered with existing automotive practice and tradition, will change not only the way cars are manufactured but also the modes of ownership. All EV manufacturers are struggling to find ways to mitigate the high cost of the battery. New models of ownership may emerge, such as that seen in the mobile ‘phone industry, whereby a driver would pay a small or zero fee for their vehicle, but be charged the amount of miles driven. The practicality of such schemes which marry a number of disciplines requires careful investigation and they present a clear case for future pilot studies.

7.5 Potential Consequences of Inaction

As stated above there are significant opportunities for UK business to exploit a move towards electric power for the transport sector. Equally those opportunities exist in whole or in part to other countries in the EU. In many respects countries which have retained ownership of their car industries and the attendant development centres and supplier chains are at an advantage. This study has contacted companies based in Germany and France amongst others, and has found an enthusiasm for electric car development which is not dependent on any UK government interventions. The large manufacturers produce for a global market and as such will place product build and to a lesser extent development close to their major markets. This being the case there are significant risks in inaction on EVs.

7.5.1 Risks

In the absence of Government encouragement for EVs, vehicle manufacturers may view the UK as a market where their electric products will struggle to find market acceptance. This could result in them significantly delaying the development of right hand drive models in favour of left hand drive European models. This will have an impact on the UK CO_2 figures, delaying any benefits until late in the study period.

Should EV development largely take place outside the UK the automotive development sector could lose touch with mainstream developments and not be viewed as a place to direct future powertrain development work, particularly as it relates to PHEVs.

When EVs eventually become mainstream product, there is a risk of the UK losing current production as conventional vehicles are replaced by EVs. The loss of both development and production will severely impact the current UK supply chain which will have few opportunities to develop

The current vibrant powertrain manufacturing sector runs a significant risk of decreased volume as units designed for hybrids outside of the UK become more common.

Also the current embryonic EV manufacture industry in the UK could be disadvantaged and be pressured to move abroad or risk becoming uneconomic.

Eventually the lack of an EV sector will lead to a dwindling UK automotive manufacturing sector and increased imports.

7.5.2 Benefits

The benefits of inaction are less apparent. If the UK were solely focussed on CO_2 reduction rather than obtaining competitive advantage from a shift to increased electrification of the vehicle, there are some advantages that could be gained by adopting a following, rather than a leading, approach.

Inaction requires little short term financial outlay.

Inaction on EVs could allow the UK Government to seek more cost efficient methods of meeting future CO_2 targets.

Inaction results in lowered risk of backing inappropriate technology. For example, hydrogen-fuelled fuel cell vehicles (which have not been considered in the scope of this study) may develop and evolve to become the technology of choice for zero-tailpipe emission vehicles.

Encouraging usage and imports of EVs could gain CO_2 benefits at reduced financial cost. This approach presupposes that vehicle manufacturers will produce right hand drive models in volume and in time.

8 Barriers and Incentives

8.1 Summary

- The successful introduction in to the market of EVs and PHEVs is not merely an evolution of the existing vehicle market, but a transformation of it. The uptake and acceptance of EVs and PHEVs will impact upon ownership and operational behaviours.
- In the BaU scenario the penetration of EVs and PHEVs is minimal. Incentives would be required to facilitate the widespread roll out of these vehicles.
- Incentives would need to be developed to overcome the identified barriers. Different incentives may be required to affect different stakeholders and therefore any development and roll out will need to be coordinated to ensure maximum impact and prevent any conflict.
- Leasing of EVs is still poorly developed due to the lack of data and uncertainty of residual values. Creation of a common finance understanding for all parties ahead of market growth would remove a significant barrier, particularly for fleet users.
- There is a need to create a forum for the development of the UK's EV industry and market to bring together the many stakeholders involved including policy makers, vehicle manufacturers, electricity generators and distributors, technology specialists, research establishments, urban designers, transport planners etc. This would be a major step towards providing consistent and coherent industry direction to facilitate roll out.

8.2 Barriers

Below is a summary of the major barriers identified which have been divided into four categories: vehicle; user; electricity infrastructure; and regulation.

8.2.1 Vehicle

8.2.1.1 Purchase Price

The current high cost of batteries is a significant barrier to the uptake of EVs and PHEVs. Although whole life running costs of EVs and PHEVs may over time become lower than ICVs, the capital cost of EVs and PHEVs will always be higher in the study timeframe due to the significant additional cost of the batteries. With current battery costs, an EV equivalent of a current production vehicle could be more than double the forecourt price. This differential is too great even for early adopters. Some price differential between EVs and equivalent ICVs in the early years would be acceptable to the early adopters and a number of vehicle distributors have indicated that this price differential would need to be less than £5,000. Many European countries offer incentives to purchase EVs – a table is included below in section 8.3.

8.2.1.2 Battery Life

The current average life of a vehicles registered in the UK is 14 years. Battery life for EVs and PHEVs is projected to reach ten years and 180,000 km; however current expectations over battery life and range are much lower. This presents the possibility of battery replacement during the life of the vehicle to ensure its continued use and brings with it significant additional cost. Given that most popular cars lose 50-60% of their purchase price after 3 years, the cost of a replacement battery is likely to exceed the value of the car, possibly leading to premature scrappage of the vehicle.

8.2.1.3 Vehicle Leasing

The high capital cost of the battery combined with the uncertainly about the battery life, reliability and obsolescence means that it is currently difficult to predict residual values for EVs and PHEVs. The vehicle and battery may also have different life expectations.

The issue of leasing would be further complicated if the battery and vehicle were separated, as a battery without a chassis may be considered worthless and vice versa.

This presents a situation where residual values cannot be predicted due to lack of in-service data for vehicles, and manufacturers are unable to get vehicles in to the market because of a lack of leasing arrangements. Vehicle leasing is a significant part of the UK vehicle market. Other models of ownership may develop to enable the uptake of EVs to become more widespread. In addition to leasing either the whole car or battery, shares ownership schemes may become more widespread. “Pay as you go” schemes similar to mobile ‘phone ownership are conceivable. This area is currently underdeveloped and the manufacturers consulted in the study offered no consensus on its future development.

Current EVs are sold using various packages. These include complete purchase, purchase of vehicle and lease of battery, and combined lease of vehicle and battery.

8.2.1.4 Vehicle Range

The current practical EV range limit is about 120 km. Although this is sufficient to cover over 93% of all two-way journeys made in the UK this is only about one fifth of the range of current ICVs. Consumers will have to adopt new “refuelling” regimes and be prepared to have to wait considerably longer than current refuelling times to enable continued use of their vehicle or to hire a long range ICV when needed. Li-ion batteries will continue to develop, offering higher energy density resulting in increased ranges to ease this problem. It is generally thought that electric cars with a comparable capability to current ICE vehicles will need a technological breakthrough, possibly only appearing towards the end of the time frame considered in this study. Until then there will be a degree of user anxiety regarding range surrounding whether there is enough charge left to complete their journey, but this should ease with familiarity and improved capability.

8.2.2 User

8.2.2.1 Running Costs

Although the whole life costs of EVs are forecast to become comparable to existing ICVs, private purchasers do not give full significance to the future running costs in the purchase decision.

8.2.2.2 Vehicle Reliability and Obsolescence

The global EV and PHEV market is currently in its infancy with technology still developing and has yet to become mature. As a result there is little firm data on vehicle reliability and vehicle life. Also with technology continuing to develop there is a concern that early vehicles may quickly become obsolete. Both of these factors affect the consumer’s confidence and leasing organisations’ ability to predict residual values.

8.2.2.3 Choice

There is no electric car on the market at present that offers the capabilities of existing fully-homologated cars in the market. Vehicles such as the G-Wiz are quadracycles with the inherent limits of vehicles in that classification. Think is planning to offer a vehicle that will be compete in the M1 class in the second quarter of 2009, and others will follow. There are currently no PHEVs available from a major OEM, but it currently seems likely that Toyota will be first to the UK market.

8.2.3 Electricity Infrastructure

8.2.3.1 Peak Charging

The preferred time for consumers to charge their vehicles is likely to be when they return home. This is both most convenient as they are already at their vehicle and also improves their travel options as they may want to use the vehicle again later and prefer the security afforded by a more fully charged battery.

The daily journey profile and evening peak generation period are closely aligned and as such could lead to significant load on the grid if this situation is not managed. Charging of vehicles overnight, during the off peak periods would need to be encouraged through electricity tariffs.

8.2.3.2 Local Distribution

EVs are likely to be owned and used in city centres. These clusters of EVs could potentially all connect to the grid simultaneously, which may require the local distribution system to be reinforced. A detailed analysis of the local situation regarding distribution should be carried out in these areas, along with a series of pilot studies to assess the real-life effects of vehicle charging.

8.2.3.3 Fast Charging

Fast charging will require an on-board charger capable of accepting higher rates of charge, which would be an additional cost on the vehicle. Fast charging may not be possible for most cars, but it could be desirable for larger vehicles such as vans and buses, using three phase power.

Simultaneous fast charging of a significant number of EVs, directly from the grid, will impact on the grid and local distribution particularly at the peak generation period. Fast charging stations used in this manner would need to be planned to reduce any grid impacts, and located in areas where distribution networks can cope or are able to be reinforced.

An alternative is to provide local energy storage (e.g. batteries or flywheels) at the charging station. These could be trickle charged from the grid at times of low grid utilisation, and provide high energy transfer rates direct from the local storage. The capital cost of the charge stations is likely to be higher using this technique, although this could be balanced by the reduced need for grid reinforcement.

Primarily fast charging should be regarded as a rare method of charging for users, for example in emergencies, and therefore can be priced accordingly to regulate its use.

8.2.3.4 Standardisation of Infrastructure

To ensure that the uptake of EVs is not hampered by issues of differing connection systems between vehicles and infrastructure, all connections should be standardised to ensure that all vehicles can make use of all available charging points.

This study found that the OEMs were unable to discuss methods of charging applicable to their potential products at this time and as such it is recommended that further work is undertaken on this.

8.2.3.5 Charging Points

The availability of charging points is unlikely to be an issue for commercial vehicles where charging can take place at the depot, but there are a number of challenges for cars.

The uptake of EVs and PHEVs will be greatest in urban environments and this will present a significant challenge for the provision of publicly-available charging points. With limited off-street parking available in cities, roadside charging points will be required to enable overnight charging and some fast charging capability in sufficient numbers to ensure their availability. Limited availability of charging points would create a supply restriction of the market. The uptake of EVs and PHEVs is unlikely to be uniform across cities, neighbourhoods or even streets, but charging points will need to be in place ahead of market uptake as no consumer would buy such a vehicle if they are unable to easily recharge their vehicle. Therefore a degree of under-utilisation of charging points would be expected as the market develops.

Current charging points cost between £5,000 and £7,000 to manufacture and install and this represents a significant cost which would need to be recouped within any business plan.

The method of connection between charging point and vehicle will need to be studied. It is envisaged that, as with the current charging points, there will need to be a cable between the charging point and vehicle and this could pose a number of issues including health and safety.

8.2.4 Skills

EV manufacture offers some fresh challenges to the UK automotive skills base. Many of the skills required to design and developed traditional ICE powered motor vehicles are transferable, including chassis and running gear design, development and assembly, with items like the body, and running gear showing little difference to an ICE powered vehicle.

The integration of the electric drive train may require a skills base development. Powertrain components such as the engine control unit (ECU) and the transmission have read across skills transfer. Skills to develop the electric motors and controllers exist in depth, but are perhaps not focused in the automotive sector. They do exist in the rail, defence and materials handling industry. However, a skills shortage may exist in the integration of the electrical and mechanical components (known as mechatronics). With traditional higher education narrowing down to either mechanical or electrical engineering, EVs present a challenge and an opportunity requiring a blend of the two disciplines.

8.2.5 Legislation

Legislation can be seen both as an enabler and as a barrier. It has been a key driver in the development of low emission technology. There was feedback from the majority of the vehicle community contacted during this study that any intervention by Government should be based on emission levels and should not proscribe technology. The Government should participate in the creation of an EU wide, long term framework to lead the progress of development, and it should provide long term clarity to enable vehicle manufacturers and their suppliers to plan and develop future technology and the vehicles to deliver the necessary solutions.

8.2.5.1 Vehicle Type Approval

Type approval is the process which ensures that vehicles, their systems and components, meet appropriate environmental and safety standards. A potential issue in a more widespread rollout of EVs in the EU and UK is how the process and regulation of type approval differs between electrically and conventionally powered vehicles.

Motorcycles and Mopeds fall within the L class of road vehicles. Motorbikes and mopeds are controlled by European type approval standards, detailed in directive 2002/24/EC of the European parliament and of the council. This directive covers combustion engine and electric drive motor cycle powertrains.

City Cars or quadracycles are lightweight vehicles intended for relatively short journeys. They are vehicles whose unladen mass is not more than 400 kg, or 550 kg for vehicles intended for carrying goods (not including the mass of batteries in the case of EVs), and whose maximum net engine power does not exceed 15 kW. These vehicles also fall within the L class of road vehicles, and so are controlled by European type approval standards, detailed in directive 2002/24/EC of the European parliament and of the Council. Many of the small EVs currently on the UK market, such as the Reva G-Wiz, fall into this category.

Standard Cars are classed as M1 vehicles. Cars powered by combustion engines and hybrid powertrains, are controlled by EC whole vehicle type approval detailed in directive

70/156/EC. Currently in the UK electrically driven cars are outside the scope of these controls, and are controlled by a national low volume type approval scheme, administered in the UK by the Vehicle Certification Agency.

However, EC whole vehicle type approval has been recently revised, and a recast directive (2007/46/EC) published. This revision means that from the 29th April 2009 electrically powered cars will be included in EC whole vehicle type approval, and must conform to the standards included in the directive.

Trucks, Vans, Bus and Coaches fall into the N and M2, M3 vehicle classes. Electrically driven trucks, vans, buses and coaches, are also outside the scope of EC whole vehicle type approval and are required to conform to the UK Construction and Use Regulations (1986) controlling the lights, tyres, brakes etc. In the case of N class vehicles, this differs from vehicles driven by ICEs, which are currently required to conform to UK national type approval.

From 2014 electrically powered trucks, vans, buses and coaches will be included in EC whole vehicle type approval, and must conform to the standards include in the directive.

All classes of vehicle – modifications to existing vehicles. Where the vehicle is based on an existing chassis, a modification to electric drive before registration requires an application to modify the approval indicating electric drive. Where modification to electric drive is post registration, an application to modify the registration document indicating the change to electric drive should be made.

All classes of vehicle – single vehicle approval. In all cases vehicles without approval may be presented to the national type approval authority for single vehicle approval (SVA). This approval requires an inspection of the vehicle presented for approval and is most suited to prototype or very low volume applications, as the process must be repeated for each vehicle.

The assessment of the type approval regulations for EVs in the UK shows a confusing mixture of approaches depending on vehicle class. This variety of approaches does not currently provide consistent support to the EV industry in the UK.

With the advent of European Community Whole Vehicle Type Approval (ECWVTA) 2007/46/EC, some simplification of matters will occur from 2009 to 2014. These regulations will provide a consistent approach to cars, commercial and public service vehicles, allowing EC wide sales of approved vehicles. However, the regulations will not cover the most predominant type of EV on the road in the EU, the quadracycle. As noted previously quadracycles are covered under the motorcycle regulation, and meet a reduced burden for type approval compared to heavier passenger cars. This quadracycle regulation is seen as a significant strength by the UK light EV community and has allowed lightweight, low power, low speed EVs to become established across the EU. It is important that this regulation continues to develop and remain fit for purpose with increasing electrification of road transport.

Arguably ECWVTA places a very significant burden on manufacturers to achieve approval, and it is designed around the needs of high speed internal combustion engine vehicles, rather than lower speed EVs. Thus, the majority of EV car manufacturers produce low specification quadracycles to lower this burden. There is a case for a developed and updated quadracycle regulation being developed to suit the requirements of future low speed electric city cars, without forcing those cars up into ECWVTA. Developing the quadracycle scope and addressing its shortcomings could provide a stimulus to new manufacturers of city cars and provide more cost effective products.

8.3 Incentives

Incentives will need to act in different timeframes and on different issues to ensure that the market is developed in a coherent manner. Care has to be taken with the announcement and introduction of any incentives to ensure that the product is market ready and able to exploit the measures and must be clearly visible in advance to allow product planning and development. It should be recognised that a mass market new vehicle product takes between four to six years to develop.

The following is a table of interventions in place around Europe for low-emission vehicles. This study is unable to uncover any evidence of the success of these measures in part due to the lack of electric cars to exploit them.

Table of European Interventions	
Norway	Electric cars exempt from car registration tax. For a B class car the registration tax is around €7,500. VAT (25%) does not apply to electric cars. Electric cars are not subject to the annual car tax of €345. EVs do not have to pay road tolls in Oslo. EVs qualify for free parking which can provide annual savings of around €2,000-€4,000. EVs are permitted to use bus lanes.
Denmark	Electric cars do not pay registration tax. Electric cars are exempt from annual car tax and qualify for free parking[53]. It is thought that further incentives will be put in place to encourage the use of EVs to coincide with the introduction of Project Better Place in 2011.
Sweden	Low or zero carbon emission vehicles get a subsidy of 10,000 SEK (€2,500)[54].
Ireland	Hybrid and flexible fuel vehicles are allowed a maximum remission of £2,500. EVs are exempt from vehicle registration tax until December 31st 2010[55].
Netherlands	Electric cars in the Netherlands are exempted from car registration tax[56].
Belgium	Belgian vehicles which emit less than 105g CO_2/km will have a €4100 reduction in registration tax[57].
Switzerland	Individual cantons provide their own EV incentives[58].
Germany	Germany is currently considering inner circle parking and congestion charge incentives for EVs similar to those in London.
France	A French initiative named Eco-pastille, which began on January 1st 2008, sees that people who buy electric cars receive €5,000 back[59]. Free parking spaces for EVs (equipped with charging apparatus) are also being reviewed.
Greece	No road tax or car registration fees for electric cars. Electric cars are also free to drive in Athens when parts of it are restricted to other vehicles to reduce traffic congestion. There is also free charging on the street of some cities[60].
Italy	Certain cities in Italy have restricted driving within the city to EVs only. Some cities also allow free parking and charging for EVs[61].
Spain	For an electric car bought in Spain €6,000 or 15% of the price of the vehicle will be returned to the customer.
Israel	The Israeli government is providing tax incentives to help Project Better Place achieve its goals. It taxes petrol cars at 72% while electric cars are only taxed at 10%[62].

Current incentives in the UK are largely centred in London, where the take up of electric cars is as great as anywhere in the world. Whilst the link between the take up and the

[53] http://www.folkecenter.net/gb/rd/transport/el_cars/
[54] http://www.sweden.gov.se/sb/d/8202/a/79866
[55] http://www.revenue.ie/
[56] http://www.defra.gov.uk/ENVIRONMENT/WASTE/thematicstrat/greeningtaxnetherlands.pdf
[57] http://www.avere.org/state_subsidies.pdf
[58] http://www.avere.org/state_subsidies.pdf
[59] http://www.lefigaro.fr/economie/2007/12/05/04001-20071205ARTFIG00283-eco-pastille-les-nouvelles-regles-du-jeu.php
[60] http://www.avere.org/state_subsidies.pdf
[61] http://www.avere.org/state_subsidies.pdf
[62] http://www.theregister.co.uk/2008/01/22/israel_electric_car_project/

interventions cannot be proven they would seem to be a major driver and an illustration of the effect such measures can have on the vehicle market.

Table of UK Interventions	
London	• London congestion charge £8 / £10 per day • Electrically propelled vehicles: 100% discount. £10 registration fee. • Up to £ 6,000 in free parking. • Alternative fuelled vehicles: 100% discount (so long as vehicles meet emission standards. Over 3,500 kg = Euro III. Under 3,500 kg = 40% cleaner than Euro IV). £10 registration fee. • Vehicles with 9 or more seats: 100% discount. • Motor tricycles: 100% discount (must be 1 metre or less in width and 2 metres or less in length). £10 registration fee. • Roadside recovery vehicles: 100% discount. £10 registration fee. • Note: Congestion zone residents get 90% discount.
UK Wide	• Zero Vehicle excise duty. • Reduction in the percentage (of P11D vehicle price) used to calculate Benefit in Kind company car tax (-3% for PHEVs, -6% for EVs). • Significant tax differential between electricity and liquid hydrocarbon automotive fuels. • Enhanced capital allowances for companies purchasing electric and low carbon cars.

The uptake of EVs and PHEVs may follow the classic adoption model of innovators, early adopters, early majority, late majority and laggards and this must be taken in to account when developing any incentives to overcome the identified barriers. Any incentives aimed to reduce these barriers should be phased in to match the market uptake, and address the differing priorities of the innovation adoption segments. A timeline of incentives could be developed and modelled to gauge impact upon the market.

To support this new automotive opportunity, there are two groups that need to be incentivised: the manufacturers and the consumers. These need to be developed together to ensure that supply meets demand and vice versa.

Manufacturers

- The introduction of EVs will encompass not only the vehicles themselves but also a complete support infrastructure – such as servicing, charging points at socially convenient locations, dedicated parking and smart payment for electricity. The development of such supporting services needs to be managed to ensure that it helps to lead the roll-out of the new technology.
- As has been identified elsewhere in this report, the UK has a significant automotive development industry, with world class capability. This expertise can make a valuable contribution to the development of UK EV capability, but it needs to be focussed and funded to do this.
- The creation of a forum for the development of the UK's EV industry and market to bring together the many stakeholders involved including policy makers, vehicle manufacturers, electricity generators and distributors, technology specialists, research establishments, urban designers, transport planners etc would be a major step towards providing coherence and industry direction to facilitate roll out. The exact aims and

scope of this forum should be the subject of further work to ensure that it is able to provide maximum benefit.

- Research should be directed towards batteries, ICEs for hybrids, electric motors, control systems, energy recovery systems and battery recycling, but this must not damage other areas of expertise and ongoing development such as powertrain.
- A clear legislative landscape must be set with regard to environmental standards with due consideration of how EVs and PHEVs would be included to maintain incentives and secure CO_2 savings. It is also unclear at this time how the 2012 EU CO_2 directive will be applied to vehicle fleets and how EVs will be credited. This clarification will need to be undertaken *via* engagement with European Union.
- There is a need to further develop relationships with existing UK manufactures and also to attract new manufacturers to the UK as a healthy manufacturing base draws in suppliers, expertise and funds for R&D. All manufacturers aim to produce final product as close to their main markets as possible to reduce transport costs which are significant for built cars. Strong support for EVs promoting a vibrant market coupled with financial initiatives for UK manufacture can be a powerful attraction for any new EV venture targeting Europe for production and sales.

Consumers

- EVs carry a significant cost penalty due to high battery cost, and without incentivisation up-take will be very limited. Within the EU there are a wide range of incentives (see table in 8.3), whilst in the UK incentives include zero VED, enhanced capital allowances and the lowest rate of company car tax, in addition to local initiatives covering issues like parking and free access. It is important to stress that any incentive should be part of a long term strategy with clear, advanced visibility and introduction to encourage EV manufacture and uptake; changes to those incentives whether positive or negative, will have an immediate affect on the values of the existing parc. This will impact not only private owners but also fleets and lease companies and the vehicle manufacturers themselves.
- The financing of EVs and/or batteries is still poorly developed due to lack of data and uncertainty of residual values. Creation of a common financing understanding for all parties ahead of market growth would remove a significant barrier.
- It is essential that the deployment of charging infrastructure for EVs and PHEVs remains ahead of vehicle uptake. A shortage of charging points would reduce consumer uptake. Early deployment with, for example, free charging using renewable energy at supermarkets, workplaces and other publicly-accessed parking places could help to drive demand.
- Incentives, such as environmental policy frameworks to encourage the uptake of EVs in major cities, should be structured on common premises to facilitate consumer understanding, although actual details may vary from city to city.
- Incentivised charging rates should be considered to ensure that vehicle charging does not impact on peak electricity demand.
- The public needs education on whole life vehicle operating costs enabling EVs and PHEVs to compete on a more balanced approach.
- The development and roll out of any incentives will need to be coordinated and timetabled to ensure maximum impact and prevent any conflict.

9 Adoption Routes

9.1 Summary

- There are a large number of stakeholders willing to be involved in vehicle deployment trials and a growing UK supply chain capable of supplying vehicles and systems. However, it is currently not clear whether there is sufficient capital funding available to fully realise the potential of these projects.
- Pilot projects will be critical to address the questions and concerns of all stakeholders involved in PHEV and EV in order to provide an evidence base for a possible future wider rollout of vehicles.
- The choice of the correct market niche and user group is critical to the success of these trials. The trials need to have clearly stated aims, with independent verification of results and outcomes and widespread dissemination of results.
- There are a number of potential UK pilot projects but none as yet stand out for special attention
- Potential pilot projects fall into two categories:-

  manufacturer led, based in a central flagship location or centre of demonstration.

  regional demonstrations supported by a network of interested stakeholders, with the activities of the network coordinated by a 'virtual' centre of demonstration.

- Interventions will be needed to promote the wider rollout of EV beyond small demonstration. These interventions will be most effective initially with captive vehicle users (ie users who are given vehicles as part of their job) rather than individual users.

9.2 Introduction

There have been a number of detailed studies on potential adoption routes for EVs based on previous vehicle deployment experience in the UK and internationally[63]. Organisations contacted during this research study also shared views on potential pathways to promote the take up of EV and PHEV. In considering the previous work with the views of the companies consulted a number of common themes and key messages emerged as being important determinants in the eventual adoption of EV and PHEV. This section attempts to categorise and explore some of these themes in a UK context before discussing potential UK pilot and demonstration project activities.

9.3 Approaches to Electric Vehicle Introduction

High-level approaches to bring EV and PHEV to market can be categorised as follows[64]:

- Motor Industry-led 'technology trial-technology push' approaches, exemplified by industry-led European deployment projects seen in La Rochelle and Ruegen Island
- Top down approaches in which policy makers try to drive the pace of deployment of EVs *via* regulatory push, exemplified by the Californian Zero Emission Vehicle mandate
- Bottom up approaches whereby interested communities provide a market-pull to deployment of EVs. An example of this was provided by Mendrisio in Switzerland where a localised\regionalised incentive structure generated a local niche vehicle supply and demand.

[63] See for example: Experimenting for Sustainable Transport, R. Hoogma et. al, Routledge, 2002; Deployment Strategies for Hybrid, Electric and Alternative Fuel Vehicles, IEA, 2002 http://www.ieahev.org/pdfs/annex_8_final_report.pdf; Hybrid Electric and Battery Electric Vehicles: Measures to Stimulate Uptake, AEA/SEI, 2008 http://*www.sei.ie/getFile.asp?FC_ID=3708&docID=59*

[64] Experimenting for Sustainable Transport, R. Hoogma et. al, Routledge, 2002.

For these differing adoption routes a series of factors can either accelerate or decelerate the rate of adoption. At the critical early market entry phase, the most influential factors are:

- Vehicle manufacturer product development timescales
- Incentive structures
- The role of sponsors and stakeholders
- The role of pilot projects.

These issues are discussed in more detail below.

9.3.1 Product Development Timescales and the Electric Vehicle Supply Chain

As discussed in section 4, the rapid rate of development of batteries for the mobile phone and portable electronics sectors has led to lithium batteries and battery chemistries offering improved power and energy density. Alongside this jump in performance of battery technology, through the development of the first generation of hybrids, the motor industry has established critically important knowledge and know-how related to the design of vehicles to best utilise battery performance and life. Motor industry players are also taking steps to secure the supply chain management for advanced battery development and supply, including the establishment of joint ventures with specialist battery producers (eg Toyota with Panasonic and Nissan with NEC).

Pure battery EVs have been considered by the mainstream motor industry to be too risky a product to market (based largely on a high initial capital cost) for a vehicle offering compromised performance (principally on range) compared to an ICV. As a consequence the majority of vehicle manufacturer R&D programmes have been focused on HEV development for near market deployment and on fuel cell development for mid-long term deployment.

At the present time industry sources indicate that only a few vehicle manufacturers have EV programmes including the potential for battery EV deployment in near term product plans – notably Nissan, Mitsubishi, Mercedes *via* smart and Suzuki. Product development, supply chain development and investment in manufacturing assets mean that there is an anticipated lead time of at least four to five years before mass marketing of EVs developed by these programmes. For other vehicle manufacturers with less well developed programmes and supply chains the lead time will be longer. For this reason the marketing of EVs in the UK by mainstream vehicle manufacturers is not expected to commence until at least 2012, with a possible ramping up in vehicle availability and supply from 2015.

PHEV represent a further development on currently available hybrids. All the mainstream vehicle manufacturers have active hybrid development programmes and hybrids in their product plans. Although there are currently a limited number of petrol hybrids marketed in the UK, and no commercially available full diesel-electric hybrids, over the next five to ten years the availability of HEVs and PHEVs is forecast to increase significantly based on vehicles known to be in product planning cycles.

The ability to accelerate this deployment is restricted by investment and product planning timescales. The increased availability of EV and PHEV depends on both the niche vehicle and mainstream vehicle manufacturers. In the UK it is clear that niche players, at least in the commercial vehicle sector, are pioneering the EV market to be followed later by the OEMs.

The emerging market for battery powered EVs is focused in two main areas: city cars and light commercial vehicles (vans). These vehicles are predominately supplied by niche vehicle manufacturers (eg G-Wiz via REVA, NICE via Aixam, Modec, Allied Vehicles and Smith Electric Vehicles) meeting a market need that mainstream vehicle manufacturers are not currently servicing, aside from limited trials. A number of UK companies from within the niche vehicle sector have been innovative in their approach to sourcing EV technology (such as batteries and motors) for vehicle development. Companies including Allied

Vehicles, Modec and Smith Electric Vehicles are among a new breed of entrepreneurs working with suppliers such as Axeon and Zytek to offer the range of EVs to UK and European markets.

9.3.2 Incentive Structures

The existence of an emerging EV market in the UK owes much to the incentive structures that – through the combination of local and national policy initiatives – have seen the beginnings of an EV market in London. The structures take the form of a collection of different local and national incentives (free parking in parts of London, congestion charge exemption, lower vehicle excise duty, etc) that combine both a financial dimension (payback) to support electric city car use and a real or perceived benefit of improved 'access'. Much of the manufacturing community consulted during this study argued against specific interventions favouring EVs.

9.3.3 Stakeholders and Sponsors

During the investigation for this report, it is clear that there is a significant and growing community of interest in the wider deployment and rollout of EVs. This community includes:

- Vehicle manufacturers. In addition to the Toyota/EDF PHEV trial discussed below, industry sources indicate that there are a number of other vehicle manufacturers in the advanced stages of planning vehicle trials in the UK.
- Public sector, including local authorities who see EVs as a facilitator of local policy goals such as improving air quality, and regional development agencies who are pursuing agendas to attract investment and value to their region.
- Private sector, particularly those companies with developed corporate social responsibility agendas.
- Energy companies. These are crucial players in future EV deployment, with the London Toyota/EDF partnership providing a model for future collaborative projects.

The diversity of this community offers a role for a strong networking body, possibly the government, to engage with this expanded community of interest in order to drive forward activity in this area.

9.3.4 Market Introduction and the Role of Pilot Projects

A recent study on possible measures to stimulate the introduction of HEV and EV noted four key points in a review of UK and international experience[65]. The authors recommended that a vehicle demonstration programme should:

- Follow the steps of a normal successful market introduction programme, including the provision of strong, independent project management
- Target the right market segment
- Select the appropriate technology
- Ensure that all stakeholders are involved

During the stakeholder engagement phase of this project, the research team was able to identify a number of potential pilot projects for the wider deployment of EV and PHEV, as well as a level of latent demand for these vehicles that could manifest itself through the distributed deployment of vehicles in response to national incentives.

These potential pilot projects are typically either regional projects – sponsored by varying combinations of local authority, Regional Development Agency (RDA) and business interests – or vehicle manufacturer-led initiatives. Given the emerging (pre-commercial to early commercial) nature of the market for EV and PHEV and the developing capabilities of technology providers and regional inter-relationships between organisations (including latent

[65] Hybrid Electric and Battery Electric Vehicles: Measures to Stimulate Uptake, AEA/SEI, 2008 http://www.sei.ie/getFile.asp?FC_ID=3708&docID=59

regional supply chains), none of these potential pilot projects is significantly more advanced than any other. Therefore there are as yet no 'stand out' projects that are recommended for special attention.

9.3.5 The Role of Local and Regional Centres

The drivers for local authority interest in the wider deployment of EV and PHEV are linked to meeting policy objectives related to air quality management (via Local Air Quality Management Plans and Local Transport Plans), carbon reduction (with links being formulated to initiatives including being signatories to the Nottingham Declaration) or localised energy diversity policies. RDA involvement has typically been linked with regional economic strategy aims linked to investment strategies to support local industry.

London projects are something of a special case. They are characterised as deployment-led (ie acting as a magnet for EV and PHEV from UK and overseas manufacturers) whereas the regional projects more commonly have sponsorship interests based on synergising local demand with local supply chain capabilities. A very recent example of a London project is the newly-announced PHEV trial by Toyota in conjunction with EDF commencing in September 2008. Toyota has indicated that it intends to build on the trial by making PHEVs available to fleet customers in Europe by the end of 2009[66]. This joint vehicle-infrastructure trial shows the critical importance of vehicle manufacturers and infrastructure/energy suppliers working together to promote the wider rollout and acceptance of EV. A non-UK example is provided by the collaboration of Ford and Southern California Edison on PHEV trials in California[67].

These EV developments mirror and share the experience of project development in other low carbon vehicle sectors, as for example in hydrogen and fuel cells, where three differing categories of regional project have been identified:

- 'urban centre' seeking to meet environmental objectives (eg air quality management)
- the regional 'technology cluster' (seeking future economic benefit for the region)
- the 'remote community' seeking to link vehicle use with localised or regional renewable energy supply.

9.3.6 Linking Supply and Demand – the 'Centre of Excellence' Proposition

A number of contacted organisations identified a perceived need for a 'recognised centre' for EV/PHEV, although not always with a common definition of the structure or role of the centre. The majority of these organisations favoured a physical centre for dedicated research, development and design located at a higher education institute with a high level of competency in EV and energy technologies, within an area in which EV and PHEV off-road testing and on-road trials could easily be conducted.

The alternative approach suggested was that of a virtual centre, formed by regional projects and activities, in a 'hub and spoke' model, managed by a central resource capturing and disseminating relevant knowledge and know how from regional projects.

There is an emerging 'virtual network' of industry (technology providers), academia, business (fleet operators) and sponsors (RDAs and agencies including Cenex and the Technology Strategy Board) who are increasingly connected, with a greater awareness of each other's activities. This is facilitated by network enhancing initiatives including those of Cenex (and SMMT Foresight Vehicle) via the Low Carbon and Fuel Cell Technology Knowledge Transfer Network, and those of the Low Carbon Vehicle Partnership and other membership organisations. The Knowledge Transfer Networks, now managed by the Technology Strategy Board, offer an existing model of how such a virtual network could be coordinated.

From discussions with a number of RDAs, two possibilities have emerged.

[66] http://www.edfenergy.com/media-centre/press-news/edf-energy-and-toyota-launch-uk-trials-of-plug-in-hybrid-vehicle.shtml
[67] http://www.edison.com/pressroom/pr.asp?id=6804

- The formation of several regional pilot projects, with supporting centres of excellence (of EV/low carbon vehicle demonstration)
- A policy intervention occurs to favour a single centre of excellence within one region that links vehicle suppliers, supply chain and academia to localised fleet operations.

It is again instructive to examine the experience of the deployments of hydrogen and fuel cell vehicles in Europe. There, a tension exists between centralised centres of deployment and competitive regional interests. Motor manufacturers (supported by the European Commission) have publicly favoured a few centralised demonstration sites (as for example in Berlin and Hamburg) so as to make most efficient use of investment (given the limited number of vehicles expected to be deployed); the regions have indicated a preference for a distributed model for vehicle deployment to help support local industry interests.

For EV/PHEV the same possible tension exists. Given the potentially much larger number of EVs already available in the UK from a range of niche and mainstream manufacturers a decision to support a single centralised centre of demonstration is unlikely to preclude smaller, mirror activities from being developed in the regions.

It is noted that the Energy Technologies Institute (ETI) is considering supporting a trial of PHEVs with a view to understanding potential scenarios for decarbonisation of energy use through mass rollout of PHEVs. Any ETI approach is likely to involve inviting competitive bids from consortia to deliver its project.

9.3.7 Regional Projects Underway or in Preparation

The table below summarises some of the key UK regional activity in EV demonstration[68]. At the time of writing none of the projects has progressed beyond feasibility study stage, and there is no one project that stands out as being significantly more developed than the others. It remains unclear whether there are sufficient capital resources available to take these projects forward.

Project and Key features	Motor Industry	Energy Companies	LA	HEI	RDA
Central London • Flagship urban centre • Sponsorship interest from pioneering boroughs (Westminster, Camden) • Established recharging points • Trials already underway (Toyota/EDF PHEV)	**	**	***		
London (West) • Pioneering boroughs (eg Richmond) • Urban location		*	**		
West Midlands • Technology cluster (with urban component) • Group of interested stakeholders focused on Coventry and Warwick • Local industry including TATA, JLR and Midlands Niche Vehicle Network • Strong RDA support	***	*	**	***	***

68 Key: * – limited involvement; ** – involvement; *** – active sponsorship

Glasgow/Strathclyde • Technology cluster (with urban component) • Group of interested stakeholders focused on Glasgow (City Council, Allied Vehicles, Scottish Enterprise plus energy companies with renewables interests)	*	***	**	*	**
Newcastle • Technology cluster (with urban component) • Group of interested stakeholders including One North East, City Council, SEV and HEI	**	*	**	*	*

Key feature of a successful vehicle trial or demonstration project is that it must have clearly defined and articulated aims and objectives. It is essential that the implementation of these projects draws on the experience and lessons learned from previous deployment projects, including those conducted outside the UK. There is a requirement for strong project management and independent oversight and verification of any future trials.

10 Findings

This study has examined a variety of aspects associated with the electrification of the transport sector and has included:-

- Possible scenarios for the uptake of these vehicles
- Comparison of the life cycle emissions and environmental impacts of these vehicles with petrol/diesel vehicles
- Battery technologies for EVs
- The impact of these vehicles upon the UK electricity grid
- Opportunities to develop UK business in support of vehicle development
- Barriers to be overcome and incentives required to help stimulate the market
- Pilot projects to test and further understand the issues surrounding the mass introduction of these vehicles.

The findings from the study are:-

- EVs have the potential to offer significant carbon dioxide and greenhouse gas emissions reductions compared to conventional petrol/diesel fuelled internal combustion engines. This applies over a full life cycle, taking account of emissions from power generation and emissions relating to production and disposal. Based on the current UK grid mix there are already significant benefits of the order of approximately 40% reduction; these benefits have the potential to become much greater with further decarbonisation of the UK power mix.
- While there may be some additional carbon dioxide emissions associated with the production and disposal of EVs, as with conventional vehicles, the largest percentage of life cycle emissions are associated with the usage phase.
- EVs offer benefits of improved air quality in urban areas through zero tailpipe emissions of NO_x, SO_x and particulates. Overall emissions of NO_x and SO_x may be higher with EVs as a result of power sector emissions (principally from coal plant) – with some potential negative consequences for air acidification. These impacts would reduce over time if greater proportions of renewable power, and reductions of the use of coal power generation, become a feature of the UK power mix.
- Lifecycle water consumption is higher with EVs – this is a feature of the increased power generation associated with charging. This additional water consumption is relatively modest compared to a typical UK household's water consumption, and primarily consists of the use of untreated water for cooling towers.
- Lithium-ion batteries are expected to be the battery chemistry of choice in the medium term. There are a range of potential environmental issues associated with their production, use and disposal which require further investigation. If properly managed these issues should not prevent their widespread safe use in automotive applications.
- The supply of EV and PHEV specific components, including batteries, is expected to keep pace with increasing volumes of vehicle production and will therefore not constrain uptake.
- The lack of a UK-based manufacturer of individual cells for automotive applications means that the most significant UK business opportunity in the battery field lies in battery pack and battery system development and manufacture.
- The impact of EVs and PHEVs on the UK electricity grid has been examined and there is sufficient generating capacity to cope with the uptake assuming that demand for charging is managed and targeted at off-peak periods where there is currently surplus

capacity. This could be achieved through variable electricity tariffs related to grid demand.

- The development of smart metering systems which are able to automatically select charging times and tariffs to suit both the consumer and generating sectors will aid the management of load on the grid.
- The existing national transmission network will be sufficient to cope with the demand from vehicles. There may possibly be distribution issues where local networks are already close to capacity. In such circumstances this can be overcome with local reinforcement. The impact of vehicle charging on local networks and infrastructure is a critical area for study in future pilot and demonstration projects.
- The development of charging infrastructure will need to keep pace with the developing market to ensure consumer confidence in the ability to recharge their vehicles with minimal inconvenience. There would also be a benefit in standardising recharging systems to maximise commonality and minimise development of manufacturer specific systems.
- The UK's automotive sector has a global reputation for research and development, design engineering and manufacturing. The development of EV and PHEV technology provides an opportunity for the UK to take a lead in the development and deployment of the new technologies required.
- There is a consensus among the organisations contacted that the trend is toward the electrification of the automobile. There remains uncertainty as to the timings, the technologies and the system designs, which could include diesel electric hybrids, fuel cells, EVs and PHEVs.
- The growth of UK manufactured EVs and PHEVs is likely to begin with the niche vehicle manufacturers already active in this field and then followed over time by the volume manufacturers.
- Opportunities for UK businesses exist in the development of batteries, internal combustion engines for hybrids, electric motors, control systems, energy recovery systems and battery recycling to meet the needs of this developing market.
- There is a strong sentiment in the vehicle manufacturing community that interventions by Government should be technology neutral.
- The internal combustion engine will continue to be used over the period under consideration. Much of its on-going development will be undertaken by UK engineering companies.
- Inaction risks the future prosperity of the UK automotive sector as development and manufacturing moves to more sympathetic markets. It also potentially delays the CO_2 benefits derived from the widespread introduction of EVs.
- Leasing of EVs is still poorly developed due to the lack of data and uncertainty of residual values. Creation of a common finance understanding for all parties ahead of market growth would remove a significant barrier to future market development, particularly for fleet users.
- The successful introduction in to the market of EVs and PHEVs is not merely an evolution of the existing vehicle market, but a transformation of it. The uptake and acceptance of EVs and PHEVs will impact upon ownership and operational behaviours and these changes need to be addressed and minimised to create the most favourable market conditions possible.
- Incentives will need to be developed to overcome the identified barriers. Different incentives may be required to affect different stakeholders and therefore their development and roll out will need to be coordinated to ensure maximum impact and

prevent any conflict. There are a large number of stakeholders willing to be involved in vehicle deployment trials and a growing UK supply chain capable of supplying vehicles and systems. However, it is currently not clear whether there is sufficient capital funding available to fully realise the potential of these projects.

- Pilot and demonstration projects will be critical to address the questions and concerns of all stakeholders involved in PHEV and EV in order to provide an evidence base for a possible future wider rollout of vehicles.
- The choice of the correct market niche and user group is critical to the success of these trials. The trials need to have clearly stated aims, with independent verification of results and outcomes and widespread dissemination of results.
- There are a number of potential UK pilot projects but none as yet stand out for special attention
- Potential pilot projects fall into two categories:-
    - manufacturer led, based in a central flagship location or centre of demonstration.
    - regional demonstrations supported by a network of interested stakeholders, with the activities of the network coordinated by a 'virtual' centre of demonstration.
- Interventions will be needed to promote the wider rollout of EV beyond small demonstration. These interventions will be most effective initially with captive vehicle users (i.e. users who are given vehicles as part of their job) rather than individual users.
- The successful roll-out of EVs and PHEVs will require a large number of stakeholders to work together for the first time, for example policy makers, manufacturers, local authorities and energy providers. It will be important that all stakeholders understand the issues associated with these vehicles so that they can be addressed in a coherent manner. Without this, there is a danger that important issues may be overlooked, such as standards for charging.
- Creation of a forum for the development of the UK's EV industry and market to bring together the many stakeholders involved including policy makers, vehicle manufacturers, electricity generators and distributors, technology specialists, research establishments, urban designers, transport planners etc would be a major step towards providing consistent and coherent incentives and industry direction to facilitate roll out.

11 Recommendations

EVs have the potential to offer significant carbon dioxide and green house gas emissions reduction compared to conventional petrol/diesel fuelled vehicles. The magnitude of the reduction achieved will depend upon the number of EVs being used and the proportion of electricity generated from renewable sources. This study has examined both the impact of the grid mix and vehicle uptake scenarios.

Although EVs will start to enter the market in greater numbers their mass penetration is unlikely to happen before around 2020. The business as usual scenario shows that the without any interventions the number of vehicles will remain small and the impact on emissions reduction will be negligible. Interventions are therefore needed to stimulate both the supply and demand side of the market.

The UK's automotive industry has a global reputation for research and development, design engineering and manufacturing and the development of EVs provides an opportunity for the UK to take a lead in the development and deployment of the new technologies required. The UK is not alone in pursing these developments and a review of the complimentary developments around the world should be undertaken to help direct UK activities.

There are a number of barriers to the development, deployment and acceptance of EVs and, although none of these are believed to be insurmountable, in many cases it will require stakeholders who have not previously had to work together to consult and agree on common approaches and standards. A method to ensure that they are able to do this in an effective and coordinated manner should be sought. This should act both as forum for discussion and agreement, but also as a coordination of pilot and demonstration studies to gain real world experience and feedback.

Private investment required to overcome the barriers will only be forthcoming if there are clear indications to all stakeholders that they will be supported over the long-term. It is important to develop a roadmap of how emissions from the transport sector can be reduced over the long term and the role that EVs can play as part of this. This must consider all of the barriers to be overcome, their interactions and the timings of incentives to ensure a coherent and successful roll out which does not stall.

There is a consensus that EVs will play a significant part in the reduction of emissions, but it is likely to be only one of a range of measures. Improvements in conventional vehicle and engine design and alternative fuels such as biofuels and hydrogen will also play a future role.

This study has highlighted a number of recommendations for further work which are listed below:-

- Create a forum for the development of the UK's EV industry and market. This could either be physical or virtual, but would need to bring together the many stakeholders involved including policy makers, vehicle manufacturers, electricity generators and distributors, technology specialists, research establishments, urban designers, transport planners etc. This would be a major step towards providing consistent and coherent industry direction to facilitate roll out. The exact aims and scope of this forum should be the subject of further work to ensure that it is able to provide maximum benefit.
- The UK should build on the favourable domestic environment created by work such as the King Review to take a leading role in efforts to promote the creation of robust international standards and the sharing of international learning and experience as an essential prerequisite to the wider rollout of EVs.
- Set clear legislative landscape for 2020 and beyond with regard to vehicle efficiency standards, which will act as a driver for technological innovation. This will need to be undertaken as part of the European Union.
- Develop a 20 year roadmap for the ongoing development of EVs and PHEVs.
- Further develop relationships with existing UK manufacturers and also attract new manufacturers and high value engineering to the UK as a healthy manufacturing base draws in suppliers, expertise and funds for R&D. This must be structured to complement the existing automotive industry.
- Focus research on batteries, internal combustion engines for hybrids, electric motors, control systems, energy scavenging systems and battery recycling and ensure that this

does not damage other areas of UK expertise and ongoing development such as powertrain.

- Under take further investigation to fully understand the range of potential environmental issues associated with Li-ion batteries and methods of mitigation.
- Facilitate pilot and demonstration studies to be carried out which will enable further real-world research to be undertaken and to build market awareness and acceptance of EVs. These pilot studies should grow in size to test scale and capability.
- Seek to ensure the deployment of charging infrastructure for EVs and PHEVs remains ahead of vehicle uptake. A shortage of charging points would reduce consumer uptake.
- EVs have the capacity to act as a distributed energy storage system although there are currently issues related to access and utilisation. Further work is recommended to understand in more detail the technical challenges, business case and overall viability of such a proposition.
- Consider facilitating the introduction of complementary policy measures that drive local market development and encourages the uptake of EVs and PHEVs.
- Educate the public on whole life vehicle operating costs, enabling EVs and PHEVs to compete with internal combustion engine vehicles in a balanced fashion.
- Raise public awareness about journey profiles to help users make informed choices on vehicle requirements and selection.

12 Glossary

CCGT	Combined Cycle Gas Turbine	
DoD	Depth of Discharge	
EV	Full Electric Vehicle	These vehicles derive all their energy directly from the electricity grid and store it in onboard batteries. They have no capability to generate electrical energy themselves and require connection to the grid to replenish their batteries. (Vehicles with regenerative braking are able to recover some energy when braking).Throughout this study it is assumed that they will derive all their energy requirements directly from the National Grid.
FGD	Flue Gas Desulphurisation	
GM	General Motors	
GWP	Global Warming Potential	
HEV	Hybrid Electric Vehicle	The current range of hybrid electric vehicles has an electric motor and an ICE which is used to recharge the battery on board. The most common example of this type of vehicle is the Toyota Prius. These cars do not figure in this study as in HEV configuration they cannot connect to the Grid.
HGV	Heavy Goods Vehicle	
ICE	Internal Combustion Engine	
ICV	Internal Combustion Vehicle	
LCA	Life Cycle Assessment	
LCPD	Large Combustion Plant Directive	
LGV	Light Goods Vehicle	
Li-Ion	Lithium-Ion	
NEP	National Electricity Production (UK only)	
NiMH	Nickel Metal Hydride	
OEM	Original Equipment Manufacturer	
PHEV	Plug-in Hybrid Electric Vehicle	These are vehicles with both an electric motor and an internal combustion engine (ICE). Their batteries can be recharged either from the National Grid or by an alternator powered by the ICE. There are a number of configurations for such vehicles in terms of contribution from the two elements, but they are able to operate for significant periods of time solely on electric power. Throughout this study it is assumed that PHEVs will derive 50% of their energy directly from the Grid, and 50% from their onboard ICE. Currently there are no PHEVs on the market.
R&D	Research and Development	
SC	Supercapacitor	
Tier One	First Tier Supplier (to the Vehicle Manufacturer)	
VM	Vehicle Manufacturer	
V2G	Vehicle to Grid	

Appendix A

Life Cycle Assessment Data

A.1 Methodology

The study has used the proprietary Life Cycle Assessment (LCA) software tool – GaBi 4 - to model the following:

- The additional impacts arising from extraction of materials comprising the batteries for an EV (as data for the battery manufacture have not been found[69]).
- Use of the EV over 180,000 km[70].
- Use of petrol and diesel vehicles over the same distance (including pre-combustion processes necessary to get the fuel to the vehicle).

Since only the EV battery is considered in the model, the following assumptions are made:

- The impact of manufacture of all other parts of the vehicles is similar[71].
- End of life impacts are similar. Research shows that decommissioning of Li-ion batteries is energy intensive. As the overall impact of end of life of a vehicle is low across its life cycle (< 5%), the extra energy required is not considered to be material.

A number of scenarios have been modelled, with base figures as summarised in the table below. These scenarios are based on one car travelling 180,000 km over a 10 year life. EVs have a Li-ion battery mass of 250 kg.

Definition of Modelled Scenarios

Scenario	Definition	Reference vehicles	Fuel/Energy (per km)
2010 EV	EV powered by electricity from a 2010 Grid mix (Appendix A)	Electric	0.16 kWh
2020 EV	EV powered by electricity from a 2020 Grid mix (Appendix A)	Electric	0.13 kWh
2030 EV	EV powered by electricity from a 2030 Grid mix (Appendix A)	Electric	0.11 kWh
2010 CCGT EV	EV powered by electricity from the "marginal" power station (Combined Cycle Gas Turbine), based on life cycle	Electric	0.16 kWh
2010 Petrol	Car fuelled by petrol, including pre-combustion	1.3l petrol	0.060 litres

[69] The impact of battery manufacture itself will depend on the process used and where it is located, and may therefore vary considerably. Most of this impact is likely to arise from energy use in the process, as heat and/or electricity and therefore this is likely to be the main contributor to the impact.

[70] 180,000 km was adopted to be consistent with figures provided by Bossche et al. for EVs, as part of the SUBAT (Assessment of Sustainable Battery Technology) project. These figures are for a vehicle with a 250 kg lithium ion battery pack.

[71] The authors have previously undertaken a study to look at the greenhouse gas emissions of the powertrain for a hybrid vehicle in comparison with an ICV. This showed that the additional greenhouse gas emissions associated with manufacture and transport of additional components of the hybrid engine did not materially impact on the life cycle greenhouse gas benefits of the hybrid drive relative to the conventional drive.

2020 Petrol	Car fuelled by petrol, including pre-combustion	1.3l petrol	0.050 litres
2030 Petrol	Car fuelled by petrol, including pre-combustion	1.3l petrol	0.042 litres
2010 Diesel	Car fuelled by diesel, including pre-combustion	1.4l diesel	0.052 litres
2020 Diesel	Car fuelled by diesel, including pre-combustion	1.4l diesel	0.044 litres
2030 Diesel	Car fuelled by diesel, including pre-combustion	1.4l diesel	0.036 litres
Defra Long Term Marginal Factor EV *(Carbon Dioxide Scenario only)*	EV powered by electricity from the “marginal” power station (Combined Cycle Gas Turbine), based on Defra figure	Electric	0.16 kWh

The Grid mix applied to Scenarios 2010 EV, 2020 EV and 2030 EV are provided in the table below:

UK Fuel Mix comprising the National Grid (%)

	2010 EV	**2020 EV**	**2030 EV**	**2010 CCGT EV**
Nuclear	22.74	6	13	-
Gas	39.3	43	40	100
Coal	32.11	17	13	-
Oil	1.79	0	0	-
Hydro	1.92	1.92	1.92	-
Wind	0.32	32.08	32.08	-
Other[72]	1.82			

Source for 2020 and 2030: *Redpoint Implementation of EU 2020 Renewable Target in the UK Electricity Sector: Renewable Support Schemes*

Source for 2010: based on UK energy mix breakdown (2002).

[72] Blast furnace gas, solid and gaseous biomass, waste.

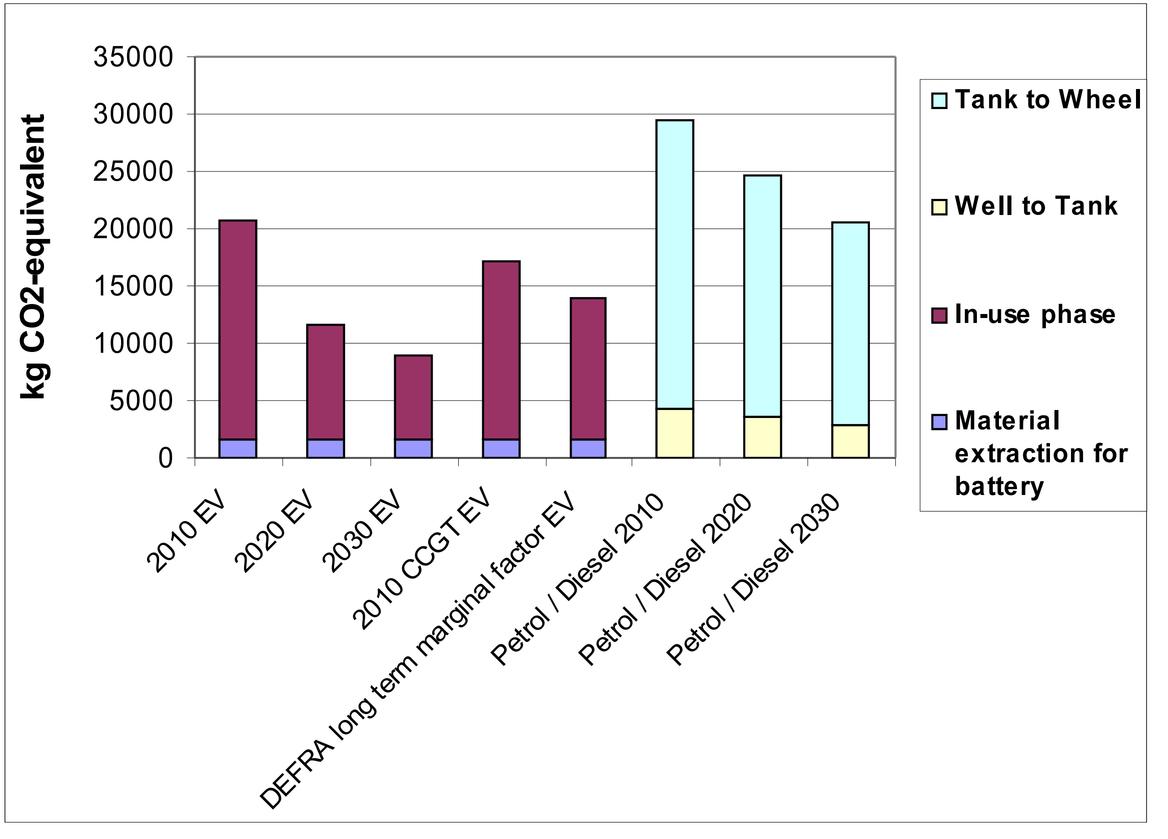
A.2 Climate & Air Quality Impacts

A.2.1 Climate Change

A.2.1.1 Comparison of in-use and Production Phases

The figure below provides a breakdown of the climate change impact caused by the EV 'in-use' phase (travelling 180,000 km in 10 years) and that caused by the extraction of the materials comprising the battery. This is compared to a petrol/diesel car, in terms of pre-combustion emissions ("well to tank") and tailpipe emissions ("tank to wheel").

With increasing supply of energy to the UK Grid from renewables, the contribution of in-use emissions to climate change impact decreases, albeit the majority of emissions (80% or more) arise from the use of the EV. Similarly, emissions for the petrol/diesel car decrease in line with greater engine efficiencies.



A.2.1.2 Table supporting Analysis of Climate Change Impacts of EV and ICV

The table below is provided in support of the analysis in Section 3. It provides the overall impact (in kg CO_2 equivalent) for the EV and ICV, and a breakdown of the significant emissions (in kg) contributing greater than 99% to the in-use climate change impact of the EV. The figures in the table below are provided for a vehicle travelling 180,000 km over a 10 year period.

	Vehicle manufactured and used in 2010					Vehicle manufactured and used in 2020					Vehicle manufactured and used in 2030				
	Electric			ICV		Electric			ICV		Electric			ICV	
	GaBi 4 factors 2010 grid mix	Defra long term marginal factor	GaBi 4 factors 2010 CCGT	Petrol	Diesel	GaBi 4 factors 2020 grid mix	Defra long term marginal factor	GaBi 4 factors 2020 CCGT	Petrol	Diesel	GaBi 4 factors 2030 grid mix	Defra long term marginal factor	GaBi 4 factors 2030 CCGT	Petrol	Diesel
Li-Ion battery production (kg CO_2 - equiv)	1,524	1,524*	1,524	-	-	1,524	1,524*	1,524	-	-	1,524	1,524*	1,524	-	-
Vehicle use (kg CO_2 - equiv)	19,161	12,384	15,669	30,916	28,012	10,132	10,062	12,731	25,864	23,435	7,390	8,514	10,772	21,639	19,606
Total	20,685	13,908	17,193	30,916	28,012	11,656	11,586	14,255	25,864	23,435	8,914	10,038	12,296	21,639	19,606
Significant in-use emissions (EV only) (kg)															
Carbon dioxide	18,101		15,335			9,624		12,460			7,042		10,543		
Methane	40.16		11.37			19.08		9.24			12.99		7.82		
Nitrous oxide	0.45		0.246			0.23		0.200			0.17		0.169		

** based on GaBi 4 emissions factors for other countries where the materials are extracted for battery manufacture*

A.2.2 Air Acidification

The table below presents the modelled results which form the basis for the analysis in Section 3. The figures in the table below are provided for a vehicle travelling 180,000 km over a 10 year period.

Air Acidification										
	Vehicle manufactured and used in 2010				Vehicle manufactured and used in 2020			Vehicle manufactured and used in 2030		
	Electric		ICV		Electric	ICV		Electric	ICV	
	GaBi 4 factors 2010 grid mix	GaBi 4 factors 2010 CCGT	Petrol	Diesel	GaBi 4 factors 2020 grid mix	Petrol	Diesel	GaBi 4 factors 2030 grid mix	Petrol	Diesel
Li-Ion battery production (kg SO_2 - equiv)	12.91	12.91	-	-	12.91	-	-	12.91	-	-
Vehicle use (kg SO_2 - equiv)	105	9.71	47	60	43.3	39	50	28.83	33	42
Total	117.91	22.62	47	60	56.21	39	50	41.74	33	42
Significant in-use emissions (EV only) (kg)										
Nitrogen oxides	38.25	10.99			16.55			11.36		
Sulphur dioxide	78.68	2.02			31.73			20.88		

- The impact of battery production will occur outside the UK if batteries are imported from countries such as China, Japan and Korea, as is currently the case.
- The results for the ICV are influenced by the sulphur content of the fuel – these results are calculated on the basis of a sulphur content of 50 ppm sulphur for petrol and 50 ppm sulphur for diesel. Sulphur content in fuels has been driven down in Europe through the Auto Oil I programme and is likely to decrease further to 10 ppm as part of Auto Oil II by 2010.

- The air acidification impact calculated for the petrol and diesel cars arises partly from emissions at the tailpipe (35% for petrol, 69% for diesel), but also as a result of emissions during the extraction, refining and transport steps needed to get the fuel to the forecourt.
- Combustion of biomass to generate energy has an air acidification impact so biomass-derived electricity supplied to the grid, would contribute to the EV impact.

A.2.3 Photochemical Oxidant Formation

Photochemical Oxidant Formation, also known as 'summer smog', is the reaction of compounds such as NO_x and VOCs with UV light. The formation is largely due to the following gases which arise in different proportions for each of the three types of vehicles listed in the table below: carbon monoxide; nitrogen oxides; sulphur dioxide; methane; NMVOCs (non-methane volatile organic compounds) to air.

- For diesel vehicles, 56% of the potential photochemical oxidant formation impact arises from tailpipe emissions. The remainder of the potential impact is primarily due to emission of NMVOCs emitted from the diesel production process.
- Similarly for the petrol vehicle, 60% of the impact is due to tailpipe emissions. 71% of the NMVOCs created are as a consequence of the fuel production process.
- For the production of battery components, which accounts for 13% of the total photochemical oxidant formation attributed to the battery EV in 2010, 73% of the impact is due to the production of the materials for the cells and current collector. The predominant gases emitted by the battery production process are sulphur dioxide and non-methane VOCs.
- As the grid mix moves towards a greater use of renewable energies, the potential impact decreases. The lowest impact arises when a CCGT is used to generate power, due to reduced sulphur dioxide emissions. For the CCGT sulphur dioxide emissions only account for 8% of the impact.

The figures in the table below are provided for a vehicle travelling 180,000 km over a 10 year period.

Photochemical Oxidant Formation										
	Vehicle manufactured and used in 2010				Vehicle manufactured and used in 2020			Vehicle manufactured and used in 2030		
	Electric		ICV		Electric	ICV		Electric	ICV	
	GaBi 4 factors 2010 grid mix	GaBi 4 factors 2010 CCGT	Petrol	Diesel	GaBi 4 factors 2020 grid mix	Petrol	Diesel	GaBi 4 factors 2030 grid mix	Petrol	Diesel
Li-Ion battery production (kg ethene - equiv)	0.98	0.98	-	-	0.98	-	-	0.98	-	-
Vehicle use (kg ethene - equiv)	6.06	1.20	11.5	6.24	2.62	9.62	5.22	1.78	8.05	4.37
Total	7.04	2.18	11.5	6.24	3.6	9.62	5.22	2.76	8.05	4.37
Significant in-use emissions (EV only) (kg)										
Carbon monoxide	8.38	3.15			3.52			2.48		
Nitrogen oxides	38.25	10.99			16.55			11.36		
Sulphur dioxide	78.68	2.02			31.73			20.88		
Methane	40.16	11.37			19.08			12.99		
NMVOC[73] to air	1.70	2.06			1.07			0.82		

[73] Non-methane volatile organic compounds

A.3 Resources and Waste

A.3.1 Non Renewable Resource Depletion

The table below presents the modelled results which form the basis for the analysis in Section 3. The figures in the table below are provided for a vehicle travelling 180,000 km over a 10 year period.

Non Renewable Resource Depletion										
	Vehicle manufactured and used in 2010				Vehicle manufactured and used in 2020			Vehicle manufactured and used in 2030		
	Electric		ICV		Electric	ICV		Electric	ICV	
	GaBi 4 factors 2010 grid mix	GaBi 4 factors 2010 CCGT	Petrol	Diesel	GaBi 4 factors 2020 grid mix	Petrol	Diesel	GaBi 4 factors 2030 grid mix	Petrol	Diesel
Li-Ion battery production (kg Sb[74] - equiv)	9.65	9.65	-	-	9.65	-	-	9.65	-	-
Vehicle use (kg Sb - equiv)	109	127.49	198	187	67.22	166	156	50.07	139	131
Total	118.65	137.14	198	187	76.87	166	156	59.72	139	131
Significant in-use emissions (EV only) (kg)										
Crude oil	290	-			35			27		
Coal	4033	-			1723			1127		
Natural gas	2324	5615			1992			1568		

The "resource depletion potentials" (equivalent to GWPs for climate change) used for this impact, are calculated based on the ratio of current levels of exploitation and known exploitable reserves.

[74] Sb – antimony

As new reserves are discovered, or become exploitable due to technological advancement or changes in economic activity, so the value of the resource depletion potentials changes. These results are based on the current resource depletion potentials available, which do not take into account the likely increased demand for lithium in the event of widespread adoption by the automotive industry.

With continued speculation about “peak oil” (the point at which half of global oil reserves have been used, at which point scarcity will gradually increase and prices rise[75]) it is likely that the resource depletion impact of ICVs will increase. Extraction of oil from other sources – such as tar sands in Canada – may potentially lead to other environmental concerns, such as increasing water consumption and greenhouse gas emissions from this energy intensive process.

[75] http://www.csa.com/discoveryguides/china/gloss.php

A.3.2 Water Use

The table below presents the modelled results which form the basis for the analysis in Section 3. The figures in the table below are provided for a vehicle travelling 180,000 km over a 10 year period.

Water use										
	Vehicle manufactured and used in 2010				Vehicle manufactured and used in 2020			Vehicle manufactured and used in 2030		
	Electric		ICV		Electric	ICV		Electric	ICV	
	GaBi 4 factors 2010 grid mix	GaBi 4 factors 2010 CCGT	Petrol	Diesel	GaBi 4 factors 2020 grid mix	Petrol	Diesel	GaBi 4 factors 2030 grid mix	Petrol	Diesel
Li-Ion battery production (litres)	11,214	11,214	-	-	11,214	-	-	11,214	-	-
Vehicle use (litres)	47,268	38,963	783	2,900	23,092	655	2,426	20,252	548	2,030
Total	58,482	50,177	783	2,900	34,306	655	2,426	31,466	548	2,030

The table below illustrates the basis for the comparison with personal domestic water consumption figures, based on water targets set out in the Code for Sustainable Homes. Code level 1 represents current standards whilst it is the Government's aim to achieve Code level 6 by 2016.

	Code 1 (Minimum standard)	Code 6 (Minimum standard)
Water consumption per person per day (litres)	120	80
Water consumption per person per year (litres)	43,800	29,200
Water consumption per person per decade (litres)	**438,000**	**292,000**

A.3.3 Waste Generation

The majority of waste generated is from overburden (material temporarily moved during mining operations) during material extraction. This waste generally does not leave site and is redeposited on-site as fill. Figures provided in the table below are provided with and without overburden, for completeness.

- Almost all the waste (excluding overburden) generated during use of the EV is radioactive waste arising from the nuclear energy component supplying the National Grid.
- Excluding overburden, 78% of the waste produced during battery production is hazardous waste, the majority (86%) of which is classed as slag and derives from the production of the white phosphate for cell production.
- In addition, other wastes generated from EVs and PHEVs relate to batteries at end of life. As the EV market is still in its infancy, there are only a few national recyclers of Li-Ion batteries in Europe. None of them have recycled lithium to its original quality at a large scale. Iron and phosphate are valuable and recoverable through the dismantling, treatment and segregation processes but recoverable lithium compounds are not of high value and have limited applications, such as lithium carbonate for the glass industry[76]. Opportunities to recycle lithium into a form that would be usable in batteries, in terms of technology and commercial application, should be investigated.

[76] Source – Accurec, a German battery recycler.

Waste Generation										
	Vehicle manufactured and used in 2010				**Vehicle manufactured and used in 2020**			**Vehicle manufactured and used in 2030**		
	Electric		**ICV**		**Electric**	**ICV**		**Electric**	**ICV**	
	GaBi 4 factors 2010 grid mix	**GaBi 4 factors 2010 CCGT**	**Petrol**	**Diesel**	**GaBi 4 factors 2020 grid mix**	**Petrol**	**Diesel**	**GaBi 4 factors 2030 grid mix**	**Petrol**	**Diesel**
With Overburden										
Li-Ion battery production (kg)	20,344	20,344	-	-	20,344	-	-	20,344	-	-
Vehicle use (kg)	25,517	218	1276	990	10,715	1068	828	7,130	893	693
Total	45,861	20,562	1276	990	31,059	1068	828	27,474	893	693
Without Overburden										
Li-Ion battery production (kg)	49.78*	49.78*	-	-	49.78*	-	-	49.78*	-	-
Vehicle use (kg)	37.59**	0.18**	1.00	0.70	7.84**	0.8	0.6	14.24**	0.7	0.5
Total	87.37	49.96	1.00	0.70	57.62	0.8	0.6	64.02	0.7	0.5

* Waste consists of 38.9kg hazardous waste, 9.7kg consumer waste and 1.18kg radioactive waste.

**Waste consists solely of radioactive waste from the nuclear industry supplying the National Grid.

A.4 Impacts to Water

A.4.1 Aquatic Eco-Toxicity (Fresh water)

This potential impact is largely due to the release of heavy metals from emissions generated by the fuel production process.

- Over 99% of the ICV total freshwater aquatic eco-toxicity impact derives from petrol and diesel production, caused primarily by release of heavy metals to the environment (92%).
- The ‘in use’ impact of petrol and diesel vehicles contributes less than 1% to the overall impact.
- The impact of the grid power mix for the EV is mainly a consequence of the use of fossil fuels, and as the renewable portion of the grid mix increases, this impact will decrease. Approximately 55% of the impact is attributable to nuclear power even though this makes up only 31% of the national grid mix in the UK. It is the increase in nuclear proportion of the grid mix that increases the impact between 2020 and 2030.

Aquatic eco-toxicity (Fresh water)										
	Vehicle manufactured and used in 2010				Vehicle manufactured and used in 2020			Vehicle manufactured and used in 2030		
	Electric		ICV		Electric	ICV		Electric	ICV	
	GaBi 4 factors 2010 grid mix	GaBi 4 factors 2010 CCGT	Petrol	Diesel	GaBi 4 factors 2020 grid mix	Petrol	Diesel	GaBi 4 factors 2030 grid mix	Petrol	Diesel
Li-Ion battery production (kg DCB - equiv)	26.5	26.5	-	-	26.5	-	-	26.5	-	-
Vehicle use (kg DCB - equiv)	29	2.39	68	29	7.18	57	24	8.72	48	20
Total	55.5	28.89	68	29	33.68	57	24	35.22	48	20
Significant in-use emissions (Kg)										
Beryllium					8E-6			6.46E-6		
Barium		0.0025			0.0019			0.0015		
NMVOCs to air (Formaldehyde)		2.06			0.089			0.817		
Heavy metals (eg Selenium, Vanadium)	0.267	0.0053			0.087			0.10		
Hydrogen fluoride								0.0051		

A.4.2 Eutrophication

Eutrophication is the absorption of excessive nutrients in a body of water, which causes a dense growth of plant life; the decomposition of the plants depletes the supply of oxygen in the water, leading to the death of animal life. The eutrophication potential is predominantly due to the emissions to air (particularly nitrogen oxides) of burning fossil fuels.

- The potential impact of the EV is related to electricity generation required to charge the vehicle's batteries. Over 95% of this impact arises from emissions to air. Of these emissions, 81% are due to use of coal supplying the National Grid in 2010. As the renewable energy proportion of the grid increases, the eutrophication potential will decrease.
- The production of battery components has only a small impact in comparison (9% of total battery EV impact in 2010), with over half of this impact attributable to production of the current collector element.

Eutrophication Potential										
	Vehicle manufactured and used in 2010				**Vehicle manufactured and used in 2020**			**Vehicle manufactured and used in 2030**		
	Electric		**ICV**		**Electric**	**ICV**		**Electric**	**ICV**	
	GaBi 4 factors 2010 grid mix	**GaBi 4 factors 2010 CCGT**	**Petrol**	**Diesel**	**GaBi 4 factors 2020 grid mix**	**Petrol**	**Diesel**	**GaBi 4 factors 2030 grid mix**	**Petrol**	**Diesel**
Li-Ion battery production (kg PO_4- equiv)	0.50	0.50	-	-	0.50	-	-	0.50	-	-
Vehicle use (kg PO_4- equiv)	5.13	1.45	4.71	8.81	2.20	3.94	7.37	1.51	3.30	6.17
Total	5.63	1.95	4.71	8.81	2.70	3.94	7.37	2.01	3.30	6.17
Major use phase emissions (kg)										
Ammonia		0.064			0.03			0.027		
Emissions to freshwater (COD)	4.45				1.92			1.30		
Inorganic emissions to air (nitrogen oxides)	38.25	10.91			16.55			11.36		

A.5 Impacts to People

A.5.1 Human Health

Most of the emissions that contribute to human health impacts are due to airborne heavy metals such as arsenic, vanadium and selenium. These primarily arise from use of coal. Another pathway occurs when heavy metals in water are consumed. The results of this analysis are as follows:

- Extraction, transport and processing of materials for battery production for the EV comprise 53% of the in-use phase impact in 2010. These potential impacts are likely to occur in regions where the materials for the batteries are sourced and processed, such as China and Japan (currently).
- Lithium oxide dust can cause irritation when breathed in and, in the worst cases, the dust can cause pulmonary oedema if inhaled. This is a risk at sites where lithium is produced. No information on the consequences of contact with lithium iron phosphate in accident situations has been found and should be investigated. People who routinely handle the batteries (such as car repairers and dismantlers) will need to observe strict health and safety procedures. Iron oxide has adverse effects on the pulmonary system and the eyes, and phosphorous oxide also harms the lungs and burns the skin. These compounds will only have an effect if the battery is damaged and has leaks.
- Use phase potential impacts of the EV arise primarily from use of coal supplying the UK National Grid and nuclear, with lesser contributions from natural gas. This potential impact arises as a result of emissions of heavy metals to air such as arsenic and selenium. This will decline with greater use of renewables supplying the National Grid – by 71% between 2010 and 2030.

Human Health										
	Vehicle manufactured and used in 2010				Vehicle manufactured and used in 2020			Vehicle manufactured and used in 2030		
	Electric		ICV		Electric	ICV		Electric	ICV	
	GaBi 4 factors 2010 grid mix	GaBi 4 factors 2010 CCGT	Petrol	Diesel	GaBi 4 factors 2020 grid mix	Petrol	Diesel	GaBi 4 factors 2030 grid mix	Petrol	Diesel
Li-Ion battery production (kg DCB[77] - equiv)	702	702	-	-	702	-	-	702	-	-
Vehicle use (kg DCB - equiv)	1,323	197	1228	496	559	1027	415	390	859	347
Total	2,025	899	1228	496	1,261	1027	415	1,092	859	347
Significant in-use emissions (Kg)										
Heavy metals to air (eg arsenic / selenium)	0.0076	0.00024			0.0041			0.0046		
Inorganic emissions to air (hydrogen fluoride / nitrogen oxides)	38.27	12.93			48.30			32.24		
Organic emissions to air (benzene)	0.037	0.09			0.032			0.025		
Emissions to freshwater (selenium / molybdenum)	0.0043									
Emissions to seawater (barium)		0.002								

[77] DCB is dichlorobenzene

Appendix B

Life Cycle of a Lithium Ion Battery

B.1 Investigation into the Life Cycle of Lithium Ion Batteries

B.1.1 Production

Production can be divided into two main stages:

- Raw material extraction (lithium, iron ore, phosphate, aluminium, copper, nickel and refinement. Aluminium, copper and nickel comprise insignificant amounts of between 0.4% and 0.006% of the total battery)
- Battery manufacture.

Transport between extraction and refinement of raw materials, as well as shipment to countries where batteries are produced, will also contribute to environmental impacts although it is not expected that these impacts will be any greater or different to existing logistics impacts.

Other components of the battery which are not specifically addressed here may include glass fibre reinforced plastic (casing), polyvinylchloride (PVC) and polypropylene (PP) (wire sheathing). Although these materials are made in energy intensive processes from a production point of view the percentage mass of these materials compared to the overall final mass of the battery are considered to be small (less than 1%)[78].

B.1.1.1 Lithium Extraction

Pre-1997, most commercial lithium was derived from mining spodumene or petalite ore which was then upgraded to a concentrate. The main lithium producers were Australia, Canada and Zimbabwe. Total world consumption was 7,000 tonnes / year.

Since 1997, increased commercial viability of lithium brine operations made spodumene a minor source of lithium. Total world lithium market consumption was estimated to be 16,300 metric tons of lithium contained in minerals and compounds in 2007.[79] The leading producers of lithium from brine are mainly in South America (Argentina and Chile), with 75% of the world's global lithium reserve base. Other big producers are China, USA, Australia and Russia. There are projections that Bolivia could become a major producer and China could be the leading producer of brine-based lithium carbonate production by 2010[80].

More than half of lithium compounds are used in the glass, ceramic and aluminium industries as a strengthening agent[81]. It is also used in the manufacture of synthetic rubber and lubricants[82]. Alternative materials can be used such as potassium (glass) and calcium soaps (grease).

The current cost of production is high but it will depend on the future costs of oil and coal, market demand, technology and extractability. The underlying rising cost of oil is likely to keep costs of lithium extraction and processing high. According to industry sources, lithium accounts for around 1.75% of a battery by weight.

Lithium dust can cause irritation when breathed in and in the worst cases, can cause pulmonary oedema (a build up of fluid in the lungs that disrupts breathing). This is more of a risk at sites where lithium is extracted.

B.1.1.2 Iron Ore Extraction

Iron occurs commonly worldwide but the main producers are China, Brazil, Australia, India and Russia. World consumption is growing at 10% per annum with the big users being

[78] Confidential source.
[79] USGS: 2007 Minerals Yearbook
[80] http://www.pr-inside.com/global-china-lithium-carbonate-industry-r690977.htm
[81] http://www.novelguide.com/a/discover/scet_01/scet_01_00028.html
[82] http://www.mii.org/Minerals/photolith.html

China, Japan, Korea, USA and the EU. A large increase in consumption could make it a finite resource[83].

The iron ore extraction industry has been consolidating since the 1970s with CVRD, Rio Tinto and BHP Billiton now controlling 35% of the global market[84].

The volumes used in battery production will have negligible effect on the total world iron requirement when compared to iron usage in other industries.

B.1.1.3 Phosphate Extraction

Phosphates are classified as non-renewable even though at current rates the depletion of economically exploitable reserves would take 100 to 300 years. There is potential conflict with agricultural use as the growth of phosphate production is coupled with the growth of modern agriculture.

About 93% of phosphate rock extracted is used to produce mineral fertilisers. Moroccan reserves account for 50% of the world total. The expected growth in world production is 1-2% per annum[85].

There is a debate as to whether high grade phosphates may run out earlier if production accelerates for applications such as in the automotive industry. However, there are contrasting views on this. Aside from demand, future production will depend on new technologies and lower costs of production of low grade phosphates.

The majority of phosphate extraction is done by the mining of phosphate rock. A 2001 report stated that the majority of phosphate rock is extracted by opencast drag-line pits (America, Morocco and Russia). Tunisia, Morocco, Mexico and India use close mining methods[86]. Common waste flows from mining include fine clay, sand tailings and significant amounts of process water. All these wastes are generally directed to rivers or other such bodies of water. The process water can be treated and reused but the main environmental issues related to phosphate mining are[87]:

- Air emissions
- Water contamination
- Noise and vibrations
- Land disturbance
- Vegetation and wildlife disturbance
- Decrease in stability of land.

B.1.1.4 Battery Manufacture

The Li-ion polymer battery currently being developed by Phostech Lithium provides an opportunity for automotive applications. Details of the Phostech Lithium manufacturing process are unavailable whilst a patent application for the technology has been filed. However, it has been developed through the University of Montreal and produces extremely fine grain lithium iron phosphate ($LiFePO_4$) particles (400 – 600 nm)[88].

The basic process is as follows:

- The lithium, iron and phosphate sources are mixed before a solid-state reactive sintering process in a controlled atmosphere.
- The process is carried out in the presence of a conductive carbon source which is heated to a very high temperature ("pyrolysis").

[83] Worldwatch Institute.
[84] The Iron Ore Market (Extract) - http://www.unctad.org/infocomm/Iron/covmar08.htm
[85] Phosphate Research Bulletin.
[86] http://www.mineralresourcesforum.org/docs/pdfs/phosphate_potash_mining.pdf
[87] http://www.mineralresourcesforum.org/docs/pdfs/phosphate_potash_mining.pdf
[88] http://www.sud-chemie.com/scmcms/web/binary.jsp?nodeId=6585&binaryId=6878&preview=&disposition=inline&lang=en

- During the process, the outer layer of material is "toasted" and the inner material reaches high temperatures in an oxygen free environment.
- $LiFePO_4$ nanofibres are produced that are coated in carbon and provide superior electroconductive performance.

Due to the high temperature, low pressure nature of the process, it is likely to be energy intensive.

B.1.2 Use

The environmental impacts of the Li-ion battery during use primarily arise from two sources:

- Charging using electricity from the National Grid.
- Replacement, due to maintenance and accidents.

B.1.2.1 Charging using Electricity from the National Grid

When a battery is charged using National Grid electricity, there is an environmental impact attached to this activity which equates to the emissions and resources consumed as a result of the underlying fuel mix supplying the Grid. These environmental impacts occur as a result of the following:

- Exploration for and extraction of fuels, such as coal, oil, natural gas and uranium.
- Transport of fuels to power stations, by tanker, truck and/or pipeline.
- Construction, operation and decommissioning of power stations (and renewables such as wind turbines and solar energy systems), including treatment/storage and disposal of wastes, ongoing maintenance and operational requirements.
- Combustion of fossil fuels.
- Fugitive emissions.
- Distribution losses arising from the Grid.

Charging with a greater proportion of renewables locally can reduce the environmental impact associated with this activity. However, biomass based schemes should ideally source material from waste biomass and should definitely be from sustainable sources that can be verified.

B.1.2.2 Replacement due to Maintenance and Accidents

Use in less than optimum conditions may result in the need to replace batteries more frequently than the designed frequency, and therefore lead to use of materials and energy required to make replacement batteries.

If the battery casing is punctured in an accident, there is a potential for health risks associated with the battery contents, although there is currently no conclusive data regarding the effects of lithium iron phosphate nano-particle materials.

Current recommendations[89] are to take sensible precautions when handling as with any unknown chemical (keep away from food stuffs, do not inhale/ingest, wash hands etc.) Effects of over exposure or extensive ecological affects are not known for the battery cells.

Health risks associated with specific materials in lithium phosphate batteries are provided below[90]:

- Lithium oxide is a severe irritant if swallowed, inhaled or in contact with skin.
- Iron oxide is harmful if inhaled (affects respiratory system), can cause inflammation of eyes.

[89] NanoProducts Corporation from http://www.coloradonanotechnology.org/home/images/stories/pdf_and_ms_word_docs/ewert%209-13%20co%20nano%20abbrev%20bus%20track.pdf

[90] http://www.coloradonanotechnology.org/home/images/stories/pdf_and_ms_word_docs/ewert%209-13%20co%20nano%20abbrev%20bus%20track.pdf

- Phosphorus oxide is toxic by inhalation, extremely hazardous and capable of causing severe burns.
- Iron phosphate is harmful to eye and respiratory system.
- Lithium phosphate is harmful when swallowed.

Further work is recommended to quantify the health risks, and set installation standards for lithium ion batteries when used to power vehicles. With best practice in the design, manufacture and installation process, and assuming normal handling precautions, there are no extraordinary hazards that might preclude the safe use of these batteries in vehicles.

B.1.3 End of Life

The disposal of batteries for hybrid cars is included in the EU Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators[91]. This Directive states that all States should achieve a high rate of collection and recycling for all types of batteries and that the recycling techniques should be the "best available" at all times. Whilst the minimum collection rate for all batteries is 45% by 2016, it is likely that much higher collection rates should be achievable through the currently established vehicle end of life route.

Batteries are not subject to the RoHS Directive (Restriction of Hazardous Substances) but are subject to the WEEE Directive (Waste Electrical and Electronic Equipment) and ELV Directive (End of Life Vehicles). As such, the recycling and/or recovery of battery components contribute to meeting of recycling and recovery targets.

The following generic waste legislation is also applicable[92]:

- Hazardous Waste Regulations 2005 – batteries are classed as hazardous waste which warrants adherence to strict rules on transport, storage and disposal.
- Environmental Protection Act 1990 – governs the way in which waste batteries are stored.
- Environmental Protection (Duty of Care) Regulations 1991 – framework for the storage, movement, recovery and disposal of batteries.
- The Waste Management Licensing Regulations 1994 – controls how the wastes are managed on land.
- The Controlled Waste (Registration of Carriers and Seizure of Vehicles) Regulations 1991 – a waste carrier must be registered with the Environment Agency.
- Land Regulations 2002 – prevents battery wastes from being put into land fill that have not received adequate 'pre-treatment' of the materials.
- The Carriage and Dangerous Goods Regulations – some battery types are classed as dangerous as well as hazardous so carrier can refuse to transport them (Li-Ion batteries are relatively safe).
- The Transfrontier Shipment of Waste Regulations 1994 – governs movement of waste between countries.

Battery recycling plants for lithium-ion batteries require the sorting of materials according to chemistries. This sorting requirement can increase transport requirements and cost[93]. Combustible material such as plastic is removed from the batteries and placed in a gas fired

[91] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:266:0001:0014:EN:PDF
[92] http://www.g-pbatt.co.uk/downloads/Legislation.pdf
[93] http://www.batteryuniversity.com/partone-20.htm

thermal oxidizer (this is a direct chemical reversal of the production process). The waste gases go through a scrubbing process before release.

Remaining material is heated to high temperatures to burn off non metallic substances and melt the remaining metal materials. The metals then settle at different positions according to density. These metals can then be recovered as separate materials or used as pig-iron for stainless steel. This process is very energy intensive and costs up to US$2,000/tonne (£1000)[94].

In the UK, one company – G & P Batteries, based in the West Midlands – recycles Li-ion batteries arising from IT applications (mobile telephones, computers, power tools etc). They currently handle 100 tonnes of Li-ion batteries per year, of which very little arises from automotive batteries.

G & P Batteries are able to recover lithium metal from primary (non rechargeable) batteries. For secondary batteries (such as those that would arise from automotive applications), it is more difficult to recover lithium salt. It can be sent to a refiner who can concentrate the salt in a solution whereby 65% of the lithium is recoverable.

Currently, the products from recycling of Li-ion batteries are lithium hydrochloride or carbonate, either of which can be used for glass making processes as a strengthening agent [95]

There are currently no recycling facilities in Europe that can recycle lithium for use in new batteries. Value for money in the recycling process is paramount and difficult to achieve at this time. For cobalt-based Li-ion batteries the cobalt content is likely to be the most valuable material.

Currently overall scrap value is not high enough to cover the costs of the recycling process fully. Accurec, a nickel cadmium battery recycling business, predicts a period of three years of research, development and experience before the recycling process is feasible.

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[94] http://www.batteryuniversity.com/partone-20.htm

[95] Private correspondence with Accurec

Appendix C

Key Players European & World, with a UK Presence

C.1 Passenger Cars

The UK plays host to a number of car companies whose brands could be major players in the electric car market.

Aston Martin – produces approximately 4,000 vehicles per annum in the Midlands; is not known to have any plans for EVs or PHEVS.

Bentley – produces 10,000 cars per annum in Crewe. It is not known to have any plans for EVs or HEVs.

BMW – all Minis for worldwide distribution are built in the UK. BMW currently builds 240,000 Minis per annum at its Cowley plant, and over 360,000 engines at its plant in Hams Hall in the Midlands. The products are no longer developed in the UK. The company is currently in the process of developing a small number of electric cars for evaluation in California.

Ford – produces nearly two million ICEs in the UK which are exported throughout Europe. Ford also manufactures the Transit in Southampton.

Honda – produces 237,000 cars per annum in Swindon. Honda also imports the Civic hybrid from the USA, which sells in small quantities in the UK.

Jaguar Land Rover – JLR produces over 320,000 premium and SUV vehicles per annum from its plants in the Midlands and Liverpool. It is working on HEVs but has no known plans for EVs.

Lotus currently produces around 2,000 cars per annum. Lotus is known to be undertaking extensive research on EVs and HEVs, but it is not known to have any plans to build them for itself although it does manufacture the Tesla.

LTI manufactures 2,500 taxis per annum.

Nanjing Automobile Corporation – has recently started producing the MG TF sports car at its facility in Birmingham.

Nissan – currently produces over 350,000 vehicles and 100,000 sets of parts at its factory in Sunderland. Many of Nissan's suppliers are located around the factory. Nissan also undertakes development of its UK manufactured vehicles in the UK at Cranfield in Bedfordshire, but not research work.

Rolls Royce – not known to have any plans for EVs or PHEVs.

SAIC – has an extensive R&D facility in the Midlands, but does not produce cars in the UK.

Toyota – produces over 277,000 cars per annum at its plant in Derby and in Deeside over 180,000 engines and 160,000 sets of parts for export. Toyota is the largest producer of HEVs in the world today, all of which are developed in Japan.

Tata – has an extensive R&D facility in the UK, including an EV group, but does not manufacture in the UK.

Vauxhall – produces 115,000 Astras per year at its plant in Ellesmere Port. GM is understood to be evaluating the feasibility of manufacturing the Volt there.

Tesla – the current vehicle is designed and built in the UK by Lotus, but not as yet sold here. Volumes for 2009 are predicted to be 2,000 vehicles.

C.2 Light Goods Vehicles

Ford – Southampton is the only Ford plant in the UK which manufactures vehicles, producing over 75,000 Transits annually. The plant's future is currently under review as Ford considers manufacturing the Transit in Turkey.

LDV produces approximately 13,000 vans per annum at its facility in Birmingham.

GM produces 95,000 vans at its Luton plant.

C.3 Heavy Goods Vehicles and Buses

Alexander Dennis - manufactures buses and coaches at its facilities in Guildford and Scotland.

Daf Trucks produces approximately 26,000 Daf and Leyland vehicles per annum for the UK market at its plant in Leyland

Optare (formerly Darwen) Group – produces buses and coaches in Leeds and Blackburn.

Dennis Eagle manufactures approximately 1,000 refuse collection vehicles per annum at its plant in Warwick.

All of the OEMs require their Tier One suppliers to be geographically close, particularly in the passenger car industry, and each of the main manufacturers has an extensive supplier park in close proximity. Many of the major Tier One suppliers are foreign owned (eg Magna, Bosch, Autoliv, Delphi, Lear, Continental), and they are only in the UK because their customers demand co-location. Without the vehicle manufacturers the suppliers would not be here, and without the supply base, the OEMs would not manufacture here. It is important to note that those suppliers who source from cheap labour markets are acutely conscious of transport costs, and any increase in fuel costs has immediate impact on their sourcing decisions, with the potential for that work to come back to the UK.

C.4 Smaller Companies

The UK has a long standing tradition of specialist vehicle development; companies such as Lotus, TVR, etc started and grew in the last century as a result of the entrepreneurial environment and the engineering capability in the UK. This sector continues to thrive with participants such as Caterham, Morgan and Westfield.

A similar burgeoning of small, enterprising companies is now occurring with the growth of EVs. These companies include:

- Allied Vehicles
- Axeon Batteries
- Evo Electric
- Lightning
- Modec
- MST (Magnetic System Technology)
- PML Flightlink
- Smith
- Zeroed

All of these companies are involved with components that are unique to electric cars – batteries, motors, control systems, much of which is currently sourced abroad. As start-ups/ SMEs, their capability to undertake research and development work is limited, and their ability to grow and prosper would benefit from access to development support. One route to this might be a cross-industry group drawn from the energy providers, vehicle manufacturers, suppliers (particularly EV systems) and engineering companies. Typically there is little contact between the energy providers and the automotive manufacturers, but this cannot be the case if electric cars are to succeed. Many of the barriers to mass introduction could be reduced or eliminated with cooperation between these sectors.

Appendix D

Companies Contacted in this Study

D.1 Companies Contacted in this Study

Allied Vehicles Group

Arval

Axeon Power Limited

BMW (UK) Ltd

Colt Car Company

Daventry District Council

EDF

Elektromotive

EON

Evo Electric Ltd

FiFe Batteries Limited

Ford Motor Co Ltd

GM Europe

G&P Batteries Ltd

Imperial College London

Jaguar Land Rover

Lightning Car Company

Lotus Engineering

Merseytravel

Modec Ltd

Nice Car Company Limited

Nissan

Prodrive

Ricardo

Road Haulage Association Ltd

Scottish and Southern Energy

Smart

Tata Motors European Technical Centre Plc

Tesla Motors

Think Global AS

Traction Technology (UK) Ltd

Toyota Motor Europe NV/SA

TRW Conekt

University College London

Warwickshire County Council

Warwick Manufacturing Group

Zeroed

Zytek

Appendix E

V2G - Vehicle to Grid

E.1 Grid Suitability for V2G

Periodically there has been interest in the concept of linking EV battery storage to the grid for purposes of demand smoothing. Recently, Volkswagen has announced a project in which eight partners are working together to demonstrate the use of renewable technologies, utilising an integrated PHEV for grid stabilization purposes[96].

Many studies have been carried out in the US where widely distributed domestic energy users make the concept attractive.

In discussion with both E.ON and Scottish and Southern Energy as part of this study, the most likely model that emerged would be to use the vehicle to smooth the house demand rather than that of the grid. In this domestic connection, the vehicle battery can trickle charge when it is efficient to do so, and be available to the house to peak-shave demand. It can also provide emergency power to the house in the event of an interruption to supply.

By keeping the smoothing downstream of the domestic meter, all electricity is effectively priced at the prevailing domestic price, which includes transmission and distribution charges. Exported energy would generally only attract a price related to the wholesale price for electricity. This would exclude the uplift to cover transmission and distribution use of system charges. Dynamic pricing may make export of electricity to the grid more attractive during periods when the wholesale price is high.

E.2 V2G Consumer Perspective

The benefit to the consumer is less apparent. Current Li-ion batteries have a cycle life of 1,000 cycles irrespective of whether they are used for transport or static needs.

The following calculation illustrates the additional cost of using the vehicle's battery as a storage device for V2G applications based on today's costs.

Currently a Li-ion battery with 35kWh storage capacity costs around £18,000 to manufacture.

With its life being 1,000 cycles, that equates to a cost per cycle of £18.00.

Assuming the charging efficiency is 92% and the battery is charged from 80% depletion at an overnight tariff of 5p/kWh, then the cost for a charge is £1.52.

Add this to the cycle cost and the cost to the owner is £19.52.

Therefore the price that the electricity would need to be bought back from the consumer to break even is £19.52 / (35 x 80%) = 69.7p

This is over ten times the cost that the consumer paid for the electricity in the first instance. This breakeven sell back rate will reduce over time as battery costs reduce.

The requirement for electricity from vehicles into the grid is only likely to happen at times of peak demand, because of the costs associated.

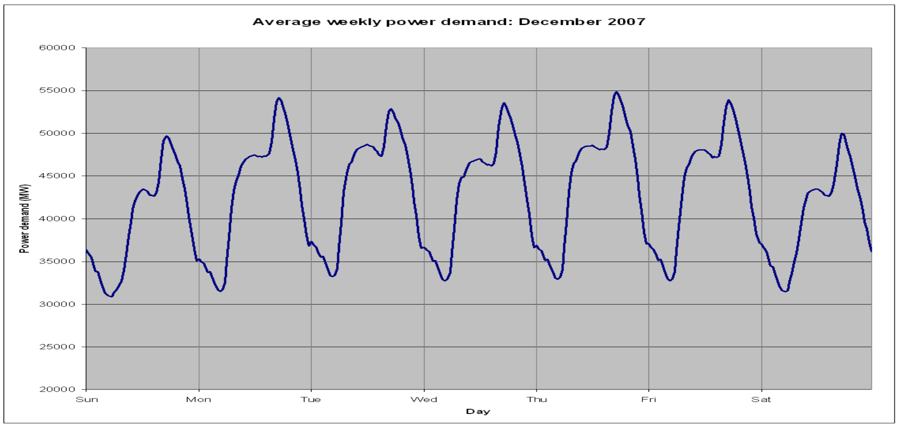
In addition to the above costs to the consumer is the cost of installing the replacement power pack. Batteries can be readily changed in vehicles with a simple architecture, but vehicles with integrated power packs to improve vehicle dynamics will not be so amenable to a swap and this operation may prove to be very costly. The extent of this cost is not known and not easily estimated without a known architecture.

[96] http://www.greencarcongress.com/2008/06/volkswagen-unve.html#more

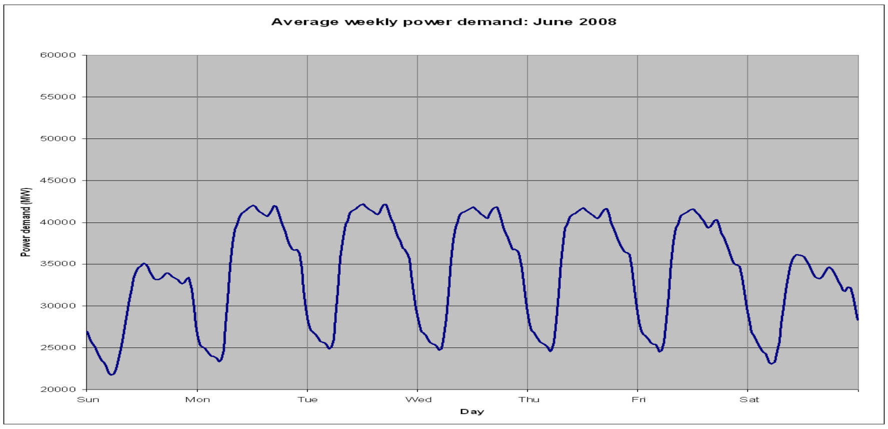
E.3 Energy Scheduling

Statistics of energy consumption are well documented and show a regular, predictable pattern.

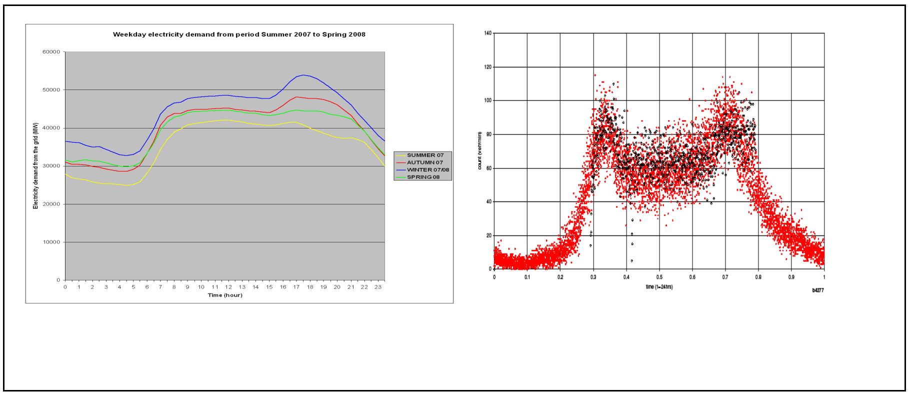
Below is the winter usage pattern over a week.



Below is a similar profile for summer usage. The lower usage profile allows plant maintenance to be carried out without impacting the overall system.



The daily travel profile in the UK is very similar to the energy usage profile. This would suggest that the optimum time to charge vehicles is at night when there is significant capacity. As discussed above smart-metering and price regimes controlled by the utility companies should help deliver an efficient distribution of energy for transport without the need for significant extra capacity beyond that currently projected.



Daily energy consumption profile Daily journey profile

The usage patterns for vehicles and the volume of energy stored in road transport would suggest that a better use for the fully-charged vehicles would be to back up domestic systems – that is not V2G but V2H (Vehicle to House). The power demand in the system is unlikely to be eased by vehicle based storage but smaller non peak spikes could be services from domestic connected vehicles.

This would be particularly useful in remote locations where supply can be threatened by adverse weather conditions and has high risk of power failure.

E.4 V2G summary

- V2G has the potential to be a useful concept in remote or vulnerable locations, when it could provide back-up power in the event of supply interruptions.
- V2G could also offer benefits to the generator in demand smoothing at peak times, by reducing demand from the grid. However, it would need to be confined to the house and not exported back to the grid where there would be significant differences in the wholesale and retail price of electricity.
- As has been stated above, the battery is predicted to have a life of around 1,000 cycles. The extra cycling of the battery as a result of being connected to the grid will bring forward the time when it has to be replaced.

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