TECHNICAL APPENDIX

The CCC developed a spreadsheet model to estimate the level of upfront support required to incentivise consumers to buy battery electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs) in the UK over the period to 2020. The model estimates the amount of support required based on the principle of negating any additional lifecycle cost incurred by purchasing an EV or PHEV, where the total subsidy is equal to the difference in the net present value of the lifetime costs of EVs/PHEVs and conventional cars, aggregated for each EV/PHEV of each type purchased.

By varying assumptions about the development of battery costs and discount rates a range of estimates for the level of subsidy was produced. This note discusses the methodology, the assumptions in the model and the results achieved.

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1. CONTEXT

In 2009 the government announced £230 million for the EV consumer incentive package: a £2,000-£5,000 subsidy per car will be offered for the purchase of an EV or PHEV. The 2009 Progress Report discusses whether this would be enough to deliver the penetration of EVs and PHEVs set out in our Extended Ambition scenario. We have looked separately at the required investment in infrastructure, so this analysis assumes that sufficient infrastructure is in place and is not a barrier to purchase of an EV or PHEV.

2. MODELLING APPROACH

The model calculates the required subsidy based on the principle of negating lifetime cost differences between EVs/PHEVs and conventional cars, where:

[Total subsidy]=([NPV lifetime cost of EV or PHEV]-[NPV lifetime cost conventional car])*[number of EVs/PHEVs]

Costs consist of both lifetime fuel costs and the cost of either a battery electric motor (for an EV), or an internal combustion engine (for a conventional car). PHEVs are treated as EVs with an additional internal combustion engine. Differences in VED or maintenance were not considered here.

We did not consider how a subsidy scheme might be structured – it may not be straightforward or desirable to offer different subsidies to cars of a different size or specification. The model is simply designed to indicate a required level of subsidy.

EVs and PHEVs are currently significantly more expensive than conventional cars, primarily due to the high cost of the battery and thus are less attractive to most consumers. If the total cost difference between an EV or PHEV and a conventional car is negated, consumers will have no reason to prefer conventional cars on grounds of cost. Initially a subsidy will be required to reach this point.

However, the costs of running an electric car are much lower than those of an internal combustion engine car, and we expect the capital costs of an electric vehicle to fall over time. This is because electric vehicles use battery technology which has yet to reach maturity; as the technology matures we expect costs to fall. Eventually a point is reached where the savings from the running costs are higher than the additional upfront costs of an electric vehicle. At this point a subsidy will no longer be required.

The total subsidy is calculated by summing the product of the number of small, medium and large EVs and PHEVs bought every year as defined in our Extended Ambition scenario by the incremental lifetime costs of each type of vehicle until the year where no subsidy is required.

3. KEY DRIVERS

The key drivers of the results from this model are the battery costs over time and the discount rate used. We looked at various assumptions for both in addition to performing a Monte-Carlo analysis to test the sensitivity of the results to the input assumptions.

Battery Costs

The future development of battery costs are a big uncertainty. However, our analysis looked at two approaches to the development of battery costs. One approach was linked costs to production volumes while the other approach linked costs to time. In the 2009 progress report we presented the results using battery costs linked purely to time as we encountered several difficulties in linking cost to volumes in an appropriate way within the model.

Batteries for powering electric cars are an immature technology. There is a general consensus that Lithium-ion batteries are the most promising technology for vehicle batteries and so this work concentrated on this type of battery. Despite similarities with batteries used for powering other electrical equipment such as laptops, the power and energy required of an electric car battery means that a significant amount of new technology has to be employed. We would therefore expect costs to fall over time as cheaper methods of producing components are found, economies of scale are realised and processes are made more efficient as manufacturers learn by doing.

Various reputable sources identified significant potential for reductions. Argonne National Laboratories and the Electric Power Research Institute performed bottom up analyses of batteries and the potential for cost reductions in each of the components. The California Air Resources Board surveyed those involved and potentially involved in the manufacture of electric vehicles to establish the current state of and future projections for battery costs. The Association of European Storage Battery Manufacturers (EUROBAT) set out a 15 year research and development roadmap with an achievable goal for battery costs at the end of that programme. All of these reports identified potential for costs to fall to $250-$300/kWh. Given current battery costs of around $1,000-$800/kWh this represent a reduction of around 70%.

The potential reductions identified in these reports arise from a combination of step changes in technology - particularly being able to use a manganese compound for the cathode, from exploiting economies of scale in production and as workers and managers learn how to produce the batteries and components more efficiently.

In reality realisation of these cost reductions will be linked to both time and production volumes. Ideally a projection of cost reductions would give some weight to both. However, we decided to adopt two approaches for simplicity and to allow us to establish a range of estimates: one approach linked cost reductions to volumes and the other to time.

The approach which links costs to time (the exogenous approach) simply has battery costs falling in a linear fashion from $1,000/kWh in 2009 to $285/kWh in 2020. This reflects the €200/kWh target set by EUROBAT. Costs fall to $150/kWh in 2030, reflecting the USABC commercialisation goal. Costs are projected beyond 2020 as we include an expected cost of a replacement battery after eight years for EVs or PHEVs.

The approach which links costs to production volumes uses a ‘learning rate’ calculated given the information about costs and production volumes in the reports discussed above. In all the reports the reductions described required a move to mass production (i.e.100,000 pieces per year) and cost estimates were given at different volumes of production. This allowed us to calculate a ‘learning rate’ of 0.84 using (2) and (3), meaning that every time production volumes double costs are reduced by 16%.

Ct = C0 x (Mt/M0)^b

LR = 2^b

Where C_0 = Marginal capital cost at beginning of time period

C_t = Marginal capital cost at time t

M_0 = Estimate of the rate of battery production at the beginning of the time period

M_t = Estimate of the rate of battery production in year t

LR = Estimate of the learning rate

ln = Natural log

This approach links cost reductions to production per year as opposed to a traditional learning approach which links cost reductions to cumulative production. This reason for this is that the reports all described production per year and this reflects the fact that the majority of the potential reductions identified were explicitly from exploiting economies of scale as opposed to learning effects. However, there are several difficulties associated with this approach.

This approach is more complex to apply within the model as the UK is only a part of the global battery market, and our work only looks at potential volumes in the UK. Clearly there will be a difference in the cost reductions between the a scenario in which the UK volumes represent the majority of EV battery production and a scenario in which UK volumes represent only a small fraction of production. Moreover, what is assumed about the market-wide production at today’s prices is important because it will significantly affect how costs develop over time.

We assume that once EVs and PHEVs begin to be sold in the UK the proportion of the worldwide sales which goes to the UK is fixed. We assume the current costs of batteries ($1,000/kWh) are equivalent to a volume of 1,000 per year in the UK. Given that the UK represents about 8% of the OECD market for conventional cars, this equates to a worldwide production of approximately 12,500. We make this assumption so that prices fall, as we expect, between now and the first year EVs and PHEVs are sold in the UK. In the first year we have EVs in the UK production of around 3,300, which equates to a worldwide production volume of around 40,000.

There is a further problem in applying this approach in that the structure of the EV market affects whether the total volume reached in the UK reflects the production volumes reached by manufacturers. Many niche producers could supply the stipulated volumes without realising economies of scale and thereby the associated cost reductions. Similarly a market with just one producer would realise economies of scale very quickly. The adoption of learning rates linked to production volumes assumes either a single producer or perfect learning spillovers between firms. Cost reductions were assumed to relate to volumes of batteries for cars of each size (small, medium and large), rather than aggregate volumes for all cars. While these assumptions are imperfect, the results are presented to supplement the exogenous approach described earlier.

We also recognised that there is a chance that batteries will require replacement during the lifetime of the car. Discussion with a number of vehicle manufacturers indicates that current battery warranties are being offered for eight years. We therefore included an expected cost of a replacement battery in the cost of the electric car. The probability of failure in the eight year of life of the new car falls over time from 1 today to 0.1 in 2020.

Discounting

The way in which people value future cost savings will significantly affect the amount of subsidy required to make electric cars at least as attractive as conventional cars. We examined three approaches to discounting: the ‘rational economic consumer’ who discounts at 7% to reflect only the real cost of capital, the ‘normal consumer’ who discounts at 20%, reflecting the requirement for a higher rate of return on operating cost savings than is typically required for other investments, and the ‘completely myopic consumer’ who discounts at 100%, giving no value to future cost savings. The higher the rate of discounting, the higher the required subsidy will be as the cost advantage of electric cars over conventional cars comes exclusively from future fuel costs.

Carbon Budgets: the need for a step change (2009) discusses ways in which consumers can be led to acting like the ‘rational economic consumer’. However the weight given to future fuel costs presents a significant risk to the efficacy of any upfront price support scheme, and the results below demonstrate a large range for required price support when varying the discount rate.

4. CARS

The model uses three sizes of conventional petrol cars, small, medium and large. These cars are differentiated by the cost of their engines, the amount of energy required to travel a kilometre and the total number of kilometres they drive per year. These are compared to small, medium and large pure electric vehicles and medium and large plug-in hybrid vehicles (small plug-in hybrid vehicles are not included as our consultants found that these were unlikely to be produced). The defining characteristics of the modelled cars are shown in Table 1.

Table 1. Car specifications

	SMALL	MEDIUM	LARGE
ICE cost (£)[a]	1,638	2,102	2,548
Battery size EV (kWh)	16[b]	35[c]	53[d]
Battery size PHEV (kWh)	-	14[e]	20[f]
Petrol car MJ/km[a]	2.2	2.5	3.8
EV MJ/km [a]	0.6	0.7	1.0
PHEV MJ/km [a]	-	0.51 (electric) & 0.52 (petrol)	0.71 (electric) & 0.73 (petrol)
km/year[a]	11,000	14,000	18,000

a. Source: AEA
b. Source: Based on the Mitsubishi i-miev
c. Source: Based on CARB (2007) required battery for a family car with good performance
d. Source: Based on Tesla Roadster
e. Source: Based on Chevrolet Volt
f. Source: Based on Fisker Karma

The assumption is that the characteristics of the conventional cars do not change over time – these assumptions are shown in Table 1. The characteristics of the EVs and PHEVs do not change either except that the cost of the battery falls over time.

Fuel costs

DECC (2009) forecasts of fuel prices were used. Fuel costs were discounted over a lifetime of 12 years as this is the average lifetime of a car.

5. UPTAKE

The uptake of EVs and PHEVs is in line with the CCC extended scenario 2009; by 2020 the cumulative penetration is 1.7 million. The uptake of different types of vehicle can be seen below. The scenarios were developed by AEA using research on planned launches of EV/PHEVs and through using the work done for DfT and BERR (now BIS) by Arup and Cenex (2008).

Results

The total subsidy under our two approaches to battery costs and three discount rates varied between £800 million and £11 billion The latter estimate reflects a myopic consumer that does not attach any weight to future fuel savings, thereby requiring an incentive equal to the full difference in upfront costs (Table 2).

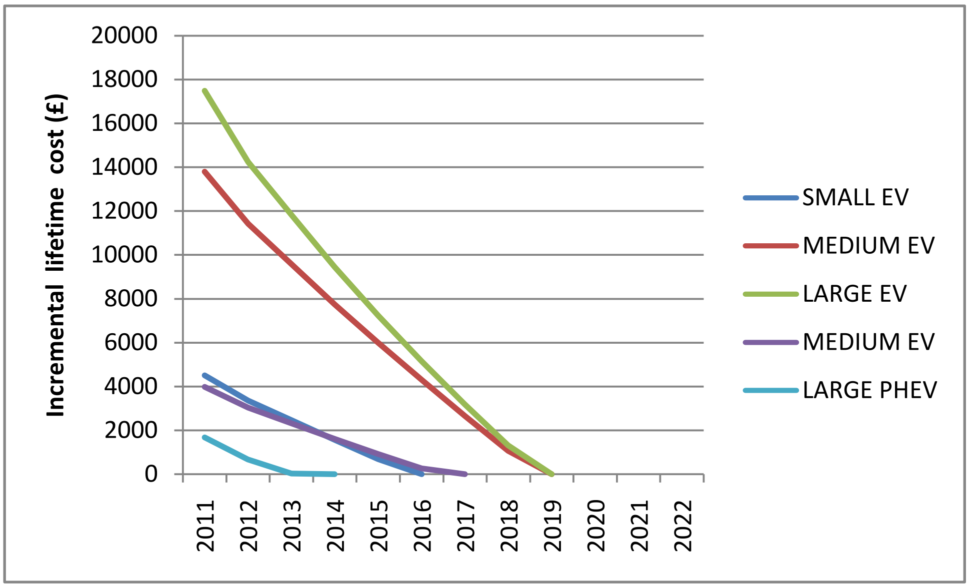
Table 2. Estimate of total subsidy

	Rational consumer	Normal consumer	Myopic consumer
Exogenous approach	£800 million	£3,400 million	£10,200 million
Learning rate approach	£1,000 million	£3,600 million	£10,900 million

Different levels of subsidy are required over time for different types and sizes of car; those with smaller batteries require less support as the battery is the main source of the additional expense. In fact under the two approaches to battery cost development the required subsidy does not vary significantly; however discounting behaviour does have a significant impact.

Figure 1 shows how the required support falls over time from the perspective of the rational consumer under the exogenous approach.

Figure 1. Incremental lifetime costs for EVs and PHEVs



NOTE: The picture includes estimates of marginal costs for years where cars of a particular type may not yet be commercially available in practice

Sensitivity analysis

We performed a Monte-Carlo analysis on the model to establish the sensitivity of the results to the input assumptions. We focussed on the ‘rational economic consumer’ to illustrate sensitivities given rational discounting behaviour. The following were allowed to vary: battery size, vehicle kilometres travelled per year, initial cost of the batteries, learning rates, the discount rate (in a range of 5-10%) and the probability of needing a battery replacement. The results are shown in Table 3 below.

Table 3. Results of sensitivity analysis

	Exogenous approach (millions)	Learning rate approach (millions)
Mean	£774	£831
St. Dev.	£803	£1,262
Mean St. Error	£15	£23
Minimum	£0	£0
First Quartile	£236	£91
Median	£517	£341
Third Quartile	£1,028	£997
Maximum	£6,113	£10,002