House of Commons Transport Committee Call for Evidence: Low Carbon Vehicles

Response to the House of Commons Transport Select Committee inquiry on low carbon vehicles from the following organisations in the *Engineering the Future* alliance:

- The British Institute of Non-Destructive Testing
- The Institution of Railway Signal Engineers
- The Engineering Council
- Engineering UK
- The Royal Academy of Engineering

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Engineering the Future is a broad alliance of engineering institutions and bodies which represent the UK's 450,000 professional engineers.

We provide independent expert advice and promote understanding of the contribution that engineering makes to the economy, society and to the development and delivery of national policy.

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Introduction

The House of Commons Transport Select Committee has invited evidence on the following five questions:

1. The contribution of plug-in vehicles to decarbonising transport.
2. Uptake of plug-in vehicles and how this can be improved.
3. The effectiveness of the Plugged-In Places scheme.
4. The role of plug-in vehicles alongside other technologies to reduce carbon emissions from road transport.
5. Action taken by other countries to encourage the uptake of plug-in vehicles.

The *Engineering the Future* alliance is not in a position to respond to Q2, Q3 and Q5 but this paper addresses questions Q1 and Q4.

The committee is referred to the Royal Academy of Engineering report *Electric Vehicles: charged with potential*[1], published in May 2010, that discusses many of these issues.

[1] www.raeng.org.uk/news/publications/list/reports/Electric_Vehicles.pdf

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Q1 – The contribution of plug-in vehicles to decarbonising transport

1. Previous work by the Royal Academy of Engineering[2] has identified that about a third of energy delivered to end users in the UK is for transport. This results in about a quarter of the UK's carbon emissions.

2. Changing from petrol and diesel vehicles to plug-in electric vehicles (EV) will, by itself, make only a limited difference to emissions. In 1997, the average CO_2 emissions of the UK car fleet was 190 g/km and while it had been much the same for several years[3], this is now down to under 150 g/km. EU targets are that the average emissions of new cars should not exceed 130 g/km by 2015 and 95 g/km by 2020.

3. In the preparation of the *Electric Vehicles: charged with potential*[1] report, the authors received evidence from engineers working in the automotive sector who said that, until the last 10 years, car designers had little incentive to save energy. Oil prices had been around $20 / barrel for more than a decade, petrol prices were dropping in real terms and customer priorities were for performance and comfort. However, since high fuel prices changed customers' perceptions, more effort has been put into reducing emissions. Whereas, a few years ago, low emissions internal combustion engine vehicles were not available across the range, it is now possible to buy models of the Mercedes B-Class, Volkswagen Touran and BMW 5 Series, all with emissions below 125 g/km. Engineers working in the industry have said that they see it entirely practicable to reduce emissions of a medium size four or five seat car to below 80 g/km[4].

4. How the emissions of a plug-in vehicle compares with those of a car with a low-emission internal combustion engine car depends on two factors: the electrical energy consumed and what fuels are used to produce the electricity.

5. Results from electric vehicle trials show that EVs equivalent to a small petrol or diesel 4-seat car use around 0.2 kWh/km in normal city traffic[5].

6. The CO_2 emissions per unit of electricity (referred to as "the carbon intensity of electricity") depends on how it is generated. Most gas-fired power stations use combined-cycle turbines and produce CO_2 emissions of around 360 g/kWh. Coal-fired power stations produce 900 g/kWh and wind turbines and nuclear power produce very low emissions (almost zero).

7. Which power stations are in use at any particular time depends on a market mechanism that prioritises low cost. In 2009, the average carbon intensity of electricity was 544 g/kWh, the following year the average was reduced, as gas was cheap, relative to coal. In the 2011-12 winter, coal has become cheaper, relative to gas, and has provided half of all grid electricity produced, thus increasing the average CO_2 per kWh.

8. There are also variations between summer and winter and between night and day. The zero-carbon producers (wind and nuclear) tend to run whenever they can produce energy. This means that, during the peaks at 6pm in the winter, the

[2] Generating the Future, March 2010
[3] There is some variation in the figures depending on exactly what classes of vehicle are defined as "cars" and whether the average takes account of the different annual mileage of small and larger cars.
[4] This emission level is approximate and does not account for factors such as refinery losses and transportation which can add another 10% or so onto the figure.
[5] This figure can only be approximate and depends on factors like the extent to which lights or air-conditioning are used.

proportion of zero-carbon electricity is lower than during a windy night in summer. Taking these factors into account, the carbon intensity of UK electricity can be more than 600 g/kWh or less than 300 g/kWh.

9. If we take an average carbon intensity of 500 g/kWh, it can be seen that an EV consuming 0.2 kWh/km is responsible for emissions of 100 g/km. This is not much different to a similar small diesel vehicle. It is likely that there will be improvements to this figure but, because an electric drive system is already efficient, in comparison with internal combustion engines, we are not likely to see dramatic improvements.

10. On this basis, it is difficult to see how EVs fed from the present UK electricity generation mix are significantly better than petrol or diesel vehicles[6]. To make a reduction in emissions commensurate with the 2050 target, the introduction of EVs must be accompanied by almost total "decarbonisation" of the electricity supply – at least at the times when they are charged (discussed below). Without low-carbon electricity, there is little point in promoting electric vehicles on environmental grounds except where the concerns are predominantly local air quality rather than purely CO_2 emissions.

Q4 – The role of plug-in vehicles alongside other technologies to reduce carbon emissions from road transport

- **Low-carbon energy**

11. An important technology that has to be developed in parallel with electric vehicles is low-carbon electricity generation. Whether this is provided by nuclear power, wind farms, tidal barrages or solar panels is of second order importance. Unlike some other uses of electricity, charging EVs has a degree of flexibility about when it is needed. But this interacts with other uses of electricity (discussed later).

12. The sources and end users of electricity in the UK are shown in Figure 1, taken from the *Generating the Future*[2] report. On the left are the various sources of energy – fossil fuels, nuclear power, intermittent renewables (such as wind and solar energy) and biomass. On the right of the diagram are the users – transport, high-grade heat (HGH, which includes furnaces and other industrial processes), electrical appliances, and low-grade heat (LGH, mainly space and water heating).

[6] It is important to ensure that comparisons between EVs and internal combustion engine vehicles compare "like with like". Some publicity compares the emissions of a basic 50 mph EV with a petrol car having air-conditioning, power steering and a top speed of 100+ mph.

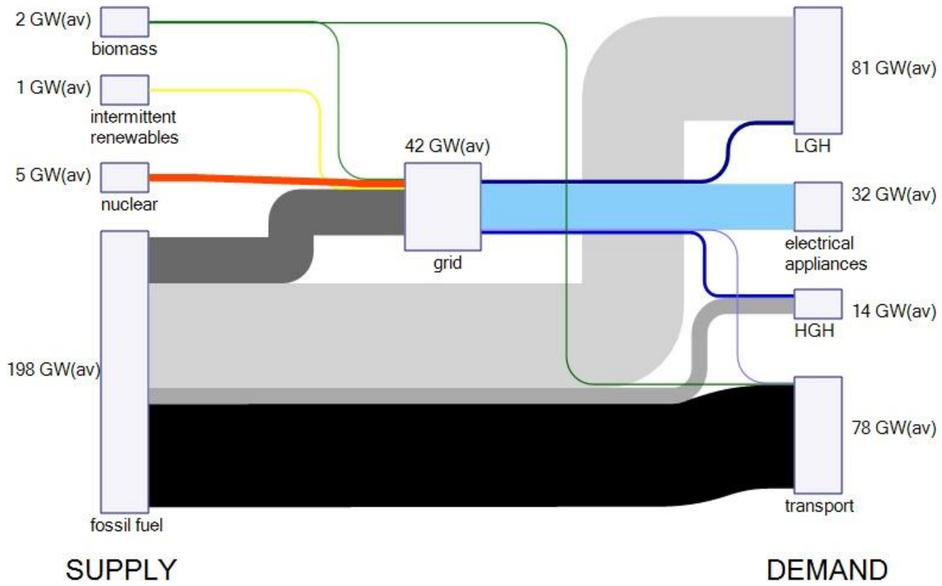

Figure 1: Energy flow chart for 2008

13. The lowest black bar represents petrol and diesel used for road transport. This illustrates the challenge that has to be met to decarbonise transport. However, it is also important to bear in mind the grey bar providing low-grade heat from fossil fuels, predominantly natural gas, used for heating. The diagram shows the average power throughout the year but, in summer, this shrinks to a low value, dominated by cooking and water heating, and in winter low-grade heat represents the highest demand on the UK's energy system – far outweighing transport.

- **Electricity storage**

14. Electricity cannot currently readily be stored, but there is increasing research activity into possible technological solutions at all levels from batteries to grid level solutions. It can be used to pump water up hill at off-peak times so the energy can be used later in peak-lopping hydro-electric generation; surplus electricity can be used to charge a battery that is later discharged back into the mains (via an inverter), or it can be used to pressurise air in an underground cavity that can be used to drive a turbo/generator when electricity is needed. However all these technologies are expensive and have losses, so the amount of energy recovered is significantly less than the amount originally stored.

15. Storing energy in the form of coal in a stockpile in a power station yard is easy, cheap and the coal doesn't deteriorate. It is possible to store several months of fuel for a large power station in this way. At the other end of the scale, storing electricity in batteries is very expensive; with currently available technology, a battery pack capable of storing a month's output of a 2GW power station with current technology would weight 20 million tonnes and cost many billions of pounds – which is not a viable option. Energy storage will be crucial to using intermittent renewables efficiently and research funding has been identified, but there are no easy solutions. It may be that technologies, such as hydrogen-powered HGVs, that considered in isolation do not seem to be particularly relevant, may provide a useful balancing mechanism to absorb excess renewable energy during the summer and provide transport during periods of shortage in winter.

16. The objective of DECC is to increase the proportion of electricity generated from low-carbon sources so that the system is largely decarbonised by about 2030. However, there are serious challenges for the UK in meeting these targets. The two major components of a low-carbon electricity supply will be nuclear power and renewables. In much of Europe, ‘renewables’ consist largely of hydroelectric generation, which can be turned on or off in a matter of minutes to respond to changes in demand. In the UK, the amount of hydroelectric power is limited, partly owing to geography, and ‘renewables’ generally means solar, tidal or wind energy. All of these sources of energy are unschedulable; either you use them when the sun is shining, the tide is flowing or the wind is blowing or you lose them.

17. The economics of renewable energy are quite different from the use of oil or gas, where fuel cost is an important, sometimes the dominant, component. For renewables, the capital costs dominate the equation and the operating costs are approaching zero. This means that the financial case for capital investment is more susceptible than fossil-fuelled stations to an intermittent market for generated electricity.

18. Figure 2 shows the load on the National Grid for two weeks – the first week of July 2009 and first week of February 2010.

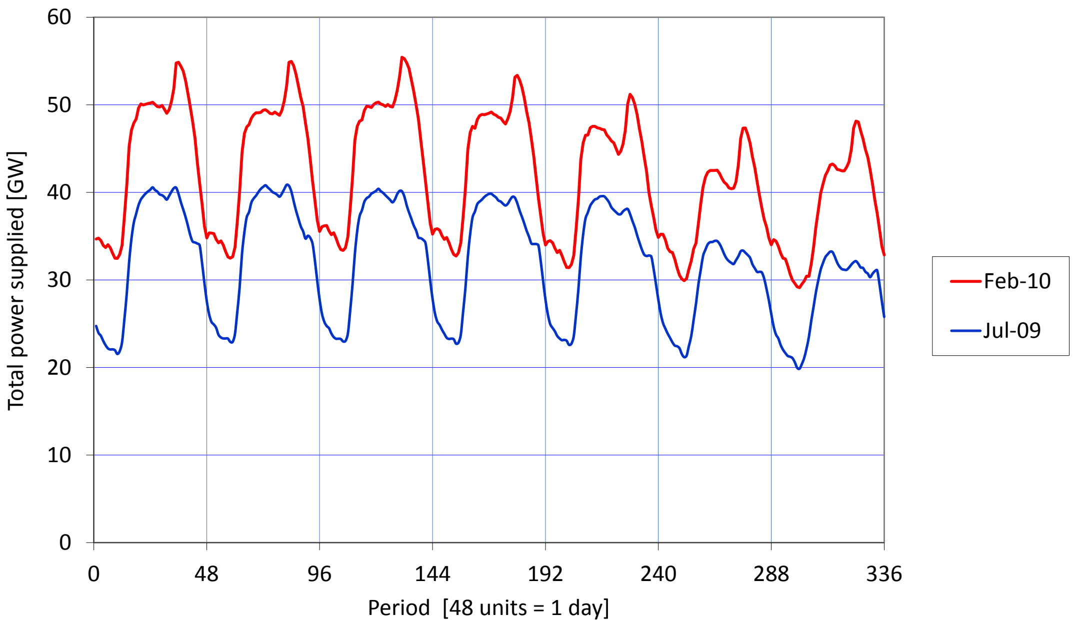

Figure 2: Load on national grid in summer and winter

19. It can be seen that the load varies from 20GW early on a Saturday morning in July to 55GW at 5:30pm on a weekday evening in February (during December 2010, the peak load was 60GW). Apart from the annual variation, there is both a weekly variation (with higher loads during the working week than at weekends) and a daily variation. The daily variation for 4 January 2010 is shown in Figure 3.

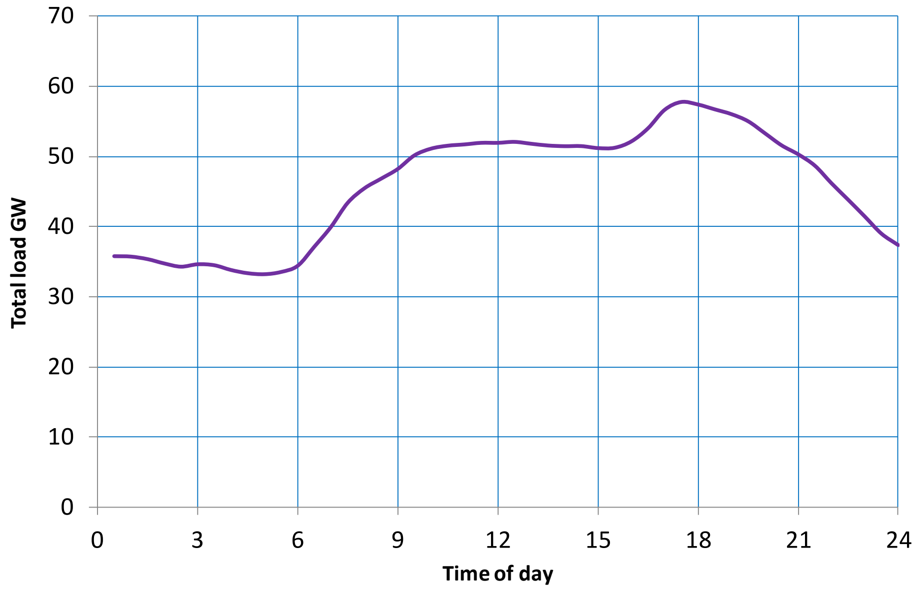

Figure 3: Demand on National Grid, 4 January 2010

20. By the mid-2020s, we expect there to be 10 new nuclear power stations, each capable of producing around 2.5 GW in addition to 30+ GW installed capacity of renewables. It is thus likely that much of the off-peak load will be met by zero-carbon generation. This will accentuate the differences in carbon intensity between day and night.

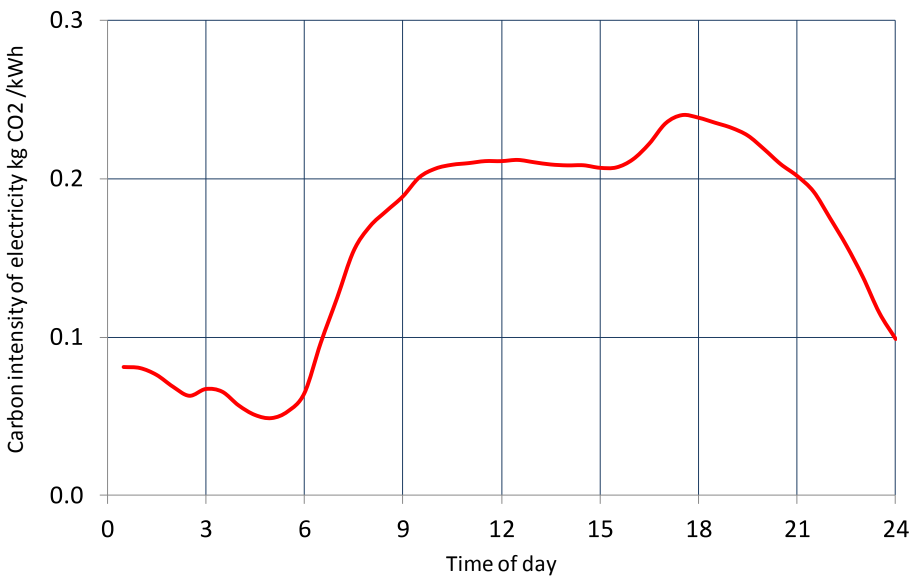

Figure 4: Carbon intensity of electricity with high renewables component

21. Figure 4 shows the carbon intensity of electricity assuming the load is the same as on 4 January 2010 and there is zero-carbon generation of 30 GW (nuclear plus wind)[7]. It can be seen that the carbon intensity varies from 50 g/kWh in the early hours of the morning to 250 g/kWh in the late afternoon. In windier conditions, the Grid could supply zero-carbon electricity from 10:00pm to 7:00am the following morning. The challenge for plug-in vehicles is to take electricity during the low-carbon

[7] Fossil fuelled generation is assumed to be mainly gas-fired with average emissions of 0.5 kg/kWh, a figure higher than the usually stated emissions of a CCGT station but that allows for the intermittent operation that would be required.

period; otherwise there is little benefit in comparison with an advanced internal combustion engine vehicle.

- **Other uses of low-carbon electricity**

22. Transport is not the only sector planning to be reliant on low-carbon electricity to meet the 2008 Climate Change Act. The CCC plans[8] for decarbonising domestic heating, accepted by government in May 2011, envisage the widespread use of electrically-powered heat pumps to replace gas boilers in millions of homes. These are likely to be supplemented by direct electrical heating, which will emphasise the peaks, and, to a lesser extent, by storage heaters which will tend to fill-in the night-time troughs.

23. The overall effect of these additional loads will be to accentuate the difference between summer and winter demand, to flatten the diurnal load cycle during the summer and to increase the "peakiness" of the diurnal cycle in the winter. We are thus likely to see a situation where the night time load can be supplied by nuclear and renewables throughout the year while the morning and evening peak load for at least six months of the year will be largely provided by gas turbine generation. During the winter, gas-fired plant is likely to be used for most of the daytime, particularly during anticyclones.

24. The significance of this is that it will no longer be possible to talk about a single figure for the carbon intensity of electricity. It will vary according to the seasons, the time of day, the weather and (if tidal energy is widely developed) the phases of the moon. It is also likely that the carbon intensity will be almost zero during much of the summer and high during the winter peaks. The marginal cost of generation will also vary. If the targets for renewable capacity are met, one could argue for electricity bills to be based only on the amount of energy drawn at peak times in winter and for summer time electricity being 'too cheap to meter'. Although such extreme commercial arrangements are improbable, it is likely that a pricing system reflecting the true costs would show dramatically different prices at different times of the day and year.

- **A new paradigm for energy use**

25. Apart from the technical and financial challenges of constructing thousands of off-shore wind turbines and tidal barrages and installing photo-voltaic panels on millions of roofs to provide low-carbon electrical energy, adopting low-carbon technologies will require a fundamental shift in how we use energy.

26. Since the power station building boom in the 1950s, the UK's electricity system has been based on the principle that the consumer is 'king' and demand has always been met by supply. In the interval of a cup final, millions of households switch on their electric kettles and, in power stations up and down the country, automatic control systems feed more coal into the boilers to provide more electricity.

27. The same principle does not work for renewables – the consumer has no control over the flow of the tides, the strength of the wind or the amount of sunlight. The supply of energy will be determined by the natural world and we will have to manage our use to match what is available.

[8] http://www.decc.gov.uk/en/content/cms/emissions/carbon_budgets/carbon_budgets.aspx

28. This need not be as draconian as it sounds as, for many applications, it is unimportant when the energy is supplied. If a commuter arrives home in the early evening and plugs in her electric car, she is unlikely to be interested whether it is charged between 10:00pm and 11:00pm or between 3:30am and 4:30am, as long as it is ready for use by 7.30am the next morning. To a lesser extent, the same is true of the space heating load. A solicitors' partnership is not concerned whether the heating has been on at a low power level since midnight or whether it has been on full-power for the previous half hour, as long as the office is warm when staff arrive at 9:00am.

- **The effect of climate variability**

29. The UK's major source of renewable energy is wind. Present plans are for around 15 GW of on-shore capacity by 2020 and a total of 18 GW of off-shore capacity[9]. However, this could make the electricity system vulnerable to a widespread anticyclone, as occurred across much of Northern Europe in January 2009. The output of UK grid-connected wind energy between 1 December 2008 and 31 February 2009 is shown in Figure 5. It can be seen that, in the second half of January, wind energy dropped almost to zero for 10 days. None of the storage technologies discussed earlier would have been able to fill this gap.

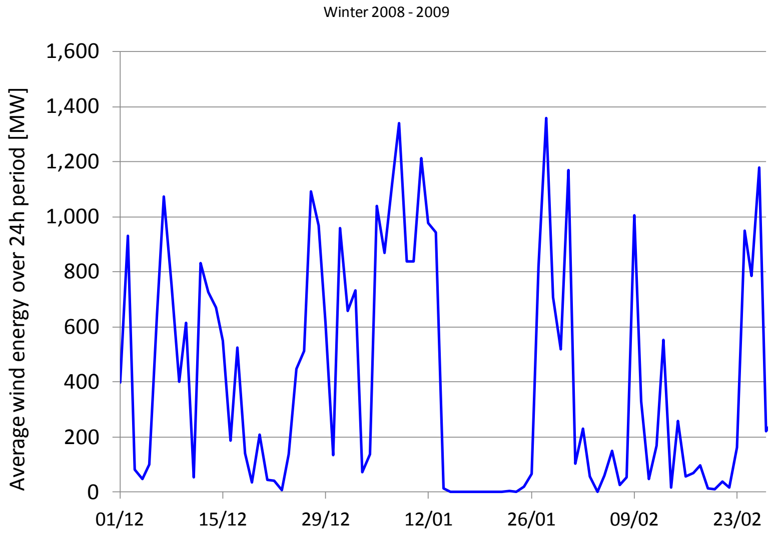

Figure 5: Daily wind energy output, winter 2008 - 2009

- **The smart grid**

30. It can be seen from the above that the use of plug-in vehicles to reduce transport emissions faces several challenges:

- If vehicles are charged at random throughout the day, the overall emissions per kilometre are unlikely to be significantly better than advanced petrol or diesel vehicles, which would be not allow the sector to meet the targets for emissions reduction.
- During the winter, the load from plug-in vehicles will be less than the load taken by heat pumps and other new heating appliances. The electricity generating and supply system will have to accommodate these loads, as well as electric vehicle charging.

[9] Data from Renewables UK

- There will be occasional periods – possibly lasting for more than a week – when weather conditions will drastically limit the amount of renewable energy. The costs of maintaining standby fossil-fuel generating capacity for this “one week a year” duty cycle would be very expensive so an alternative strategy is needed.

31. Apart from the need to manage the overall UK load to match available generating capacity, the smart grid may also be needed to “negotiate” between different users in the same local area. Figure 6 is a greatly simplified diagram to illustrate the problem.

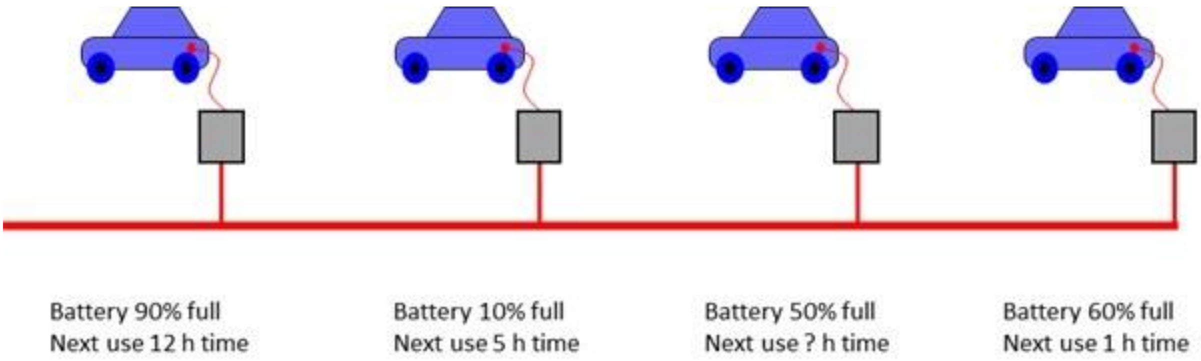

Figure 6: Electric vehicles on charge

32. In the above diagram, there are four vehicles all put on charge in the evening. The charging computers can identify the state of charge of the batteries, and it is assumed that at least some of the owners have clicked on buttons to say when they next want to use their vehicles.

33. The challenge for the local smart grid, working with intelligent battery chargers, is to ensure that:

    - All vehicles are adequately charged when needed.
    - The load on national generating capacity is within the available limits.
    - When energy is scarce, those vehicles in greatest need are given priority.
    - The load on the cables in the street is limited to what they can carry.

34. This is not an easy compromise to broker, particularly when it has to be overlaid with a mixture of different commercial contracts between electricity retailers and customers, and encouragement for consumers to search out better deals and switch suppliers within the electricity market.

- **V2G (vehicle-to-grid recuperation)**

35. Several groups have advocated not only varying the charging power to suit the availability of low-carbon electricity but also using plug-in vehicle batteries to support the grid in times of high load. The principle is that the battery charger is “put into reverse” to allow the batteries in a fleet of plug-in vehicles to provide short term back-up to allow the electricity grid to cope with demand peaks of a few hours duration or the failure of a power station or part of the transmission network.

36. However, such a scheme, although useful in supporting the grid in extreme conditions would need to be very carefully integrated with a high integrity “smart grid” to ensure the energy was only fed back when needed. Faulty software that called for

vehicle-to-grid energy transfers over a wide area when not required could wreak havoc with the protection systems on the electricity grid.

- **Road pricing?**

37. At present energy prices, there is a strong incentive for motorists owning a plug-in hybrid vehicle to use electricity in preference to petrol or diesel. For a motorist driving a car that uses 5 litres/100 km (57 mpg) on diesel or 0.2 kWh/km on electric power with energy prices of 150 p/litre for diesel and 10 p/kWh for electricity, the relative costs are 7.5 p/km for diesel or 2 p/km for electricity.

38. Government policy is to rely on the market to optimise allocation of resources. If the market is to dissuade people from using electricity to charge a plug-in hybrid at periods of low renewable energy availability, this differential will have to be reversed, implying an increase of at least five times in the price of electricity during periods of scarcity.

39. For families in fuel poverty, energy bills fluctuating by a factor of five, depending on weather patterns, is likely to be deeply unsettling and politically challenging to implement, which suggests it would be difficult to rely on the market to allocate energy resources. This points to the need for a more sophisticated taxation scheme than the traditional combination of vehicle and road fuel tax. The details of such a system that could incorporate elements of carbon pricing plus congestion charging are outside the scope of this submission. However, it should be noted that the widespread adoption of plug-in vehicles will require a different taxation model from that with which we are familiar.

Conclusions

40. Work undertaken by the Royal Academy of Engineering and professional engineering institutions over the last few years has shown that large number of plug-in vehicles, by themselves, would not necessarily result in a significant reduction in CO_2 emissions.

41. For plug-in vehicles to make a difference, they have to be introduced in parallel with low-carbon sources of energy and a "smart grid" that optimises the charging of plug-in vehicles as well as the many other new loads (including replacements for domestic heating boilers) that will be operating from the electricity grid. A smart grid with these characteristics, interfacing with home energy management computers and with the control systems for renewable energy supplies is a hugely complex system that has never been attempted before and is far removed from the "smart meters" that are about to be rolled-out across the country.

42. Key to the successful introduction of large numbers of plug-in vehicles and a consequent reduction in CO_2 from the transport sector is a new mindset that takes a systems view of the supply and use of all forms of energy. This should cover not only the transport sector but the energy used by the built environment and industry, as well as all potential supplies.

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Annex 1: *Engineering the Future* alliance members

British Computer Society
British Institute of Non-Destructive Testing
Chartered Institution of Building Services Engineers
Chartered Institution of Highways & Transportation
Chartered Institute of Plumbing and Heating Engineering
Chartered Institution of Water and Environmental Management
Energy Institute
Engineering Council
Institution of Agricultural Engineers
Institution of Civil Engineers
Institution of Chemical Engineers
Institute of Cast Metals Engineers
The Institution of Diesel and Gas Turbine Engineers
Institution of Engineering Designers
Institution of Engineering and Technology
Institution of Fire Engineers
Institution of Gas Engineers and Managers
Institute of Highway Engineers
Institute of Healthcare Engineering & Estate Management
Institution of Lighting Professionals
Institute of Marine Engineering, Science and Technology
Institute of Measurement and Control
Institution of Mechanical Engineers
Institution of Royal Engineers
Institute of Acoustics
Institute of Materials, Minerals and Mining
Institute of Physics
Institute of Physics & Engineering in Medicine
Institution of Railway Signal Engineers
Institution of Structural Engineers
Institute of Water
Nuclear Institute
Royal Aeronautical Society
Royal Institution of Naval Architects
The Welding Institute
Society of Operations Engineers
Society of Environmental Engineers