TRANSPORT

TRANSPORT POLICY STATEMENT: 10/02

ELECTRIC VEHICLE RECHARGING INFRASTRUCTURE

Institution of MECHANICAL ENGINEERS

The UK Government has made a commitment to reduce CO_2 emissions by 80% in a little over four decades. Transport currently produces about a quarter of the UK's total CO_2 emissions, with road transport contributing over 80% of this. However, mobility is essential: it drives economic growth and societal development and we cannot just put a stop to travelling. We must therefore opt for solutions offering the greatest emissions reductions from the 31.4 million cars and vans on our roads.

The Institution firmly believes that electric vehicles are an important part of the UK's motoring and low-carbon future. In its 4th Carbon Budget[1] the Committee on Climate Change warned that the entire car stock needs to be electric in order to meet the Climate Change Act's 2050 CO_2 reduction target. To achieve this, all new vehicles need to be electric by 2035. This would require significant penetration by 2030, given limits on scope for accelerating the pace of take up.

We are entering a period during which choices about EVs and their enabling infrastructure will have a significant impact on the long term viability of EVs. The availability of appropriate charging facilities will be a vital part of this.

The Institution recommends that:

1 Government should play a central role in creating co-operation among local authorities to ensure consistent EV infrastructure strategies;

2 Strategic planning authorities should prioritise the introduction of workplace Level 1 chargers;

3 Manufacturers should work together to create and use consistent standards and protocols for charging and billing;

4 Government and manufacturers should work together to fund and undertake research into reducing 'rapid charge' times.

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RECHARGING INFRASTRUCTURE

INCREASING DEMAND

In various configurations, electric vehicles (EVs) are likely to form a significant part of a low-carbon transport future. However, sales of EVs have so far been low. The main reasons for this have been the relatively high capital costs of EVs, their limited range and performance, and a limited availability of cars and charging facilities[2,3].

Change is, however, taking place. Policy interventions offer help with capital costs[i]; rapid engineering-led progress means that EV range is increasing and operating performance is moving towards that of conventional vehicles. As a result, EVs from 'mainstream' manufacturers are now arriving in the showrooms. From early 2011, consumers will have a wider choice, albeit initially limited, of EVs from some of the big names in vehicle manufacturing. At the same time EV trials and demonstrator schemes continue as part of the ongoing development and awareness-raising process. Announcements about EV developments are occurring frequently and regularly.

Estimates suggest that about 3.1 million EVs will be sold globally between 2010 and 2015. The roll-out of EVs will require a supporting infrastructure of recharging facilities. Schemes have been launched to provide public charging facilities in major urban areas around Europe, and London is one of the leaders in this work.

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BY 2015 AN ESTIMATED 4.7 MILLION EV RECHARGING POINTS WILL BE INSTALLED GLOBALLY GENERATING ANNUAL REVENUES IN THE REGION OF £1.4 BILLION.

PIKE RESEARCH REPORT; 2010.

CO_2 IMPLICATIONS

Under a 2030 scenario where the UK has 15.9 million EVs, and these vehicles are responsible for 45% of all car-km travelled, up to 16Mt of CO_2 per year will be saved relative to the baseline. (This assumes an average grid CO_2 intensity of about 0.14kgCO_2/kWh.) This CO_2 saving represents 30% of 2030 baseline emissions from cars in the UK, or about 2.7% of total 1990 CO_2 emissions. Should EVs be recharged with electricity just from fossil-fuelled power stations, the CO_2 savings are reduced to about 5MtCO_2/yr. Even then, this figure may be increased to about 8.5MtCO_2/yr if the peak demand for electricity due to EVs could be offset to correspond to periods of lower overall electricity demands.

Source: Strategies for the uptake of electric vehicles and associated infrastructure implications; Element Energy for The Committee on Climate Change, Final Report; October 2009.

i The UK Government currently offers a £5,000 plug-in car grant – effectively a contribution to the vehicle purchase price. EV purchase prices look likely, however, to be relatively high for some time.

KEY ISSUES – VEHICLE USE AND RANGE

EVs have limited range performance compared to equivalent conventional vehicles powered by an internal combustion engine (ICE). This is due to the low energy density of batteries compared to petrol and diesel. For comparison, two major EVs launched in the UK in 2010 – the Mitsubishi i-MiEV and the Nissan Leaf – have a maximum range under 'normal' driving conditions[ii] of about 100 miles. A diesel-powered ICE car of similar size has a typical range of about 500 miles per tank of fuel[iii].

The DfT National Travel Survey for 2009 shows that annual car mileage is decreasing (despite car ownership increasing). Annual average business mileage has, for example, fallen by 47% between 1995/97 and 2009 (1,710 miles to 900 miles), while commuting mileage fell by 11% in the same period[4]. The average annual distance travelled per person per year by car is now 5,468 miles; this equates to about 15 miles per day, although people make more trips per day at the weekend than during the week. The vast majority (94%) of trips by car/van are of less than 25 miles; 98% of journeys are of less than 50 miles[5]. The overall number of miles per car is falling and, even allowing for variation within averages, the majority of UK car/van journeys are short trips. The top three purposes of travel, measured by the number of trips per person per year, are[6]:

Shopping	193 trips
Commuting	147 trips
Visiting friends	109 trips

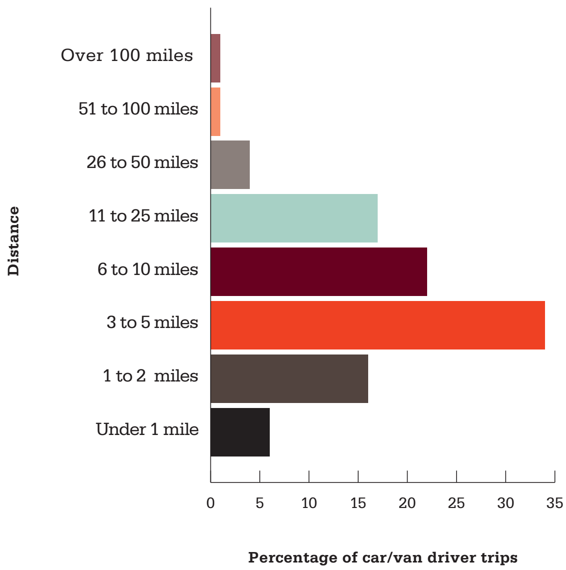
However, the distance travelled in miles for each of these trip types is:

Commuting	1,266 miles
Visiting friends	1,111 miles
Shopping	833 miles

It is, therefore, important to distinguish between trip type and distance. In doing so, we can conclude for example, that a vehicle with a utilised[iv] range of 100km (about 62 miles) would be sufficient for over 90% of trips made and 60% of overall UK car miles. Assuming a range of 80km, 50% of all UK vehicle-km can be undertaken by EVs[7]. The remaining distance is undertaken by a relatively small number of high-mileage individuals.

Despite this, people appear anxious about the relatively low range of EVs between charge and recharge. On average, between one third to one half of the technical range is actually used, i.e. a vehicle with a capability of 100-mile range will on average be used for 33–50 miles. The low utilisation ratio is a rational response to limited recharging opportunities, long recharging times, and concerns over the reliability of new technology. This utilisation ratio needs to increase if EVs are to achieve their CO_2 reduction potential. There is evidence to suggest that widespread slow charging will have limited effect on increasing the utilisation ratio, but in contrast, fast charging can be very effective in encouraging users to exploit the vehicles' full potential.

Figure 1: Percentage of car / van driver trips by length (DfT data)



ii 'Normal' driving conditions implies driving on level ground, without excessive acceleration or speed.

iii The record is 1,526.63 miles on a single tank of fuel set in 2010 by a Volkswagen Blue Motion Passat.

iv The range a vehicle would be capable of would be much higher - in the region of double the utilised range.

CHARGING

All EVs, including hybrid EVs[v], need some form of external charging. This requires them to be linked to a supply of electricity generated outside the vehicle.

EV external recharging during transit has been suggested as an option. One example of this is induction, in which batteries of a moving EV could be charged using an electromagnetic field extended along the centreline of a driving lane. A level controlled armature mounted on the underside of an EV straddles and traverses over the magnetic field. Current is induced into the armature coils by the relative motion between the armature coils and the primary inductive coils. For billing purposes, a vehicle can be identified and timed as it enters and leaves the charging lane by means of a vehicle-mounted barcode and scanners located at the entrance and exit of the charging lane; billing information would be relayed to a data storage and process centre[8].

Problems associated with this include energy loss during transfer and, significantly, high capital cost of road adaptation and maintenance. Currently therefore most efforts continue to focus on providing links to electricity supplies that require vehicles to be static, taking on electricity from a charging facility.

a) Static facilities
The type and siting of EV charging facilities are important, as these factors affect user behaviour. They also affect the economics of charging and of planning for investment in charging infrastructure networks, etc. **Table 1** summarises charging facilities by type and location.

b) Battery swap stations
Currently, the most rapid charging option is battery swap. This is facilitated at stations similar in concept to petrol stations, with the turnaround time being similar to refuelling with liquid fuels.

This offers a logical, technically feasible response to the limitations of battery range if we want EVs to make up 100% of car miles. This would better match users' expectations of a refuelling experience, as it can take place at roadside stations – similar to refuelling with petrol and diesel.

Better Place and its EV partner Renault-Nissan are unique in that they have decided to pursue battery swapping as a key feature of the business model. They are currently working on installations in Denmark and Israel. Vehicle manufacturers other than Renault have not so far designed their EVs to accommodate rapid battery swapping capability.

Swap stations demand that a large stock of batteries is held on site. They require the standardisation of batteries and new models of battery ownership (i.e. rented rather than owned by the vehicle owner). Continued improvements in fast-charge technology will result in 'charge times' nearing 'swap times', thus reducing the advantage of battery swap. Importantly they represent an additional layer of expense (approximately £318,000 per battery swap station[9]) in addition to charging posts/domestic charging, which will be needed whether or not battery swap is adopted.

Table 1: EV charging facilities

Charging level	Typical use	Approximate charge time
Level 1 (Slow)	**Domestic:** This includes in garages of single homes and multi-unit apartment complexes as well as on street residential spaces. This already exists in most residences and can be used to charge EVs overnight. **Workplace:** This includes at outdoor office garages, commercial complex parking garages, and station car parks	7–8 hours
Level 2 (Fast) Level 3 (Rapid)	**Public:** This includes all non-home and non-office charging such as on public streets, at public garages, supermarket garages etc. Expected to be a combination of Level 2 and Level 3 charging for quick top-ups of battery power, while users shop at supermarkets, go to the cinema, or run short errands, etc.	3–4 hours 30 minutes
Battery Swap	**Station:** Facilitated at battery stations similar in concept to petrol stations.	2–3 minutes

[v] Hybrid EVs combine their electric battery with a petrol or diesel engine which can be used as a range extender or when greater power is needed.

c) Public recharging

A public, visible infrastructure would undoubtedly send strong signals to potential end-users by promoting familiarity with EVs and their charging. Indeed, there seems to be a common view that visible and widespread public recharging infrastructure must be available before EV adoption can take place.

Some, including The Committee on Climate Change[10], have questioned whether this is a technical necessity; in particular they cite the high cost involved (per kWh delivered) when compared to alternatives such as residential and workplace charging. The cost of an installed publicly available slow-charge (low kW) post could range from £6,000 (2009 prices) to £1,000–£2,000 (at volume). A fast-charge (>50kW) charging point could cost between £50,000 and £100,000, depending on the necessity for upstream grid reinforcement.

The average time spent at a destination (other than the home and the workplace) is one to two hours. In such circumstances Level 1 (slow charge) systems have limited public use, as they would provide only fractional increase in battery state of charge. For example a Mitsubishi i-MiEV and a Nissan Leaf are nominally charged in about seven or eight hours using a 220-volt supply.

Therefore, slow charge for publicly available infrastructure will have very limited benefit. Fast-charging points will be much more useful to most users and will go some way towards removing the time 'barrier' associated with recharging.

To avoid complexity and to promote convenience for users, publicly available recharging posts must be interoperable, using a common standard. Such fast-chargers are already being developed; about 150 are already installed in Japan, and Nissan plans a further 200. In Europe, SGTE Power, Epyon and Evtronic are making fast-chargers that are equipped with the latest CHAdeMO[vi] communication protocol.

d) Workplace recharging

Workplace charging will play an important role in expanding EV uptake among commuters, the sector which accounts for the highest mileage among private drivers. There are several factors in favour of using EVs for commuters.

- **Residence time**: Given that the residence time at the workplace averages seven or eight hours, workplace Level 1 (slow-chargers) can be used without affecting users. Workplace charging also provides flexibility in electricity grid management, as supply can be matched to demand during the seven or eight hours parking time; smart metering and/or delay timers could be used to facilitate this.
- **Utilisation**: Compared with public charging points, the utilisation rate of workplace chargers can be accurately predicted using known information about workplace and station car park capacity. It will also be easier to guarantee a parking spot with recharging facilities, which benefits the user and provides greater predictability of revenue for the operator.
- **Range anxiety**: The known distance of travel and confidence in the availability of charging facilities will reduce range anxiety for users.

The Committee on Climate Change estimates that the cost of a slow-charge point in a workplace environment could approach that of a domestic recharging point in new build. Even in retrofit on existing buildings, the cost should be lower than that of a publicly available point.

[vi] CHAdeMO is a quick charging method for battery electric vehicles. It is proposed as a global industry standard by the CHAdeMO association (The Tokyo Electric Power Company, Nissan, Mitsubishi and Fuji Heavy Industries – manufacturers of Subaru – and Toyota).

e) Domestic recharging
Along with workplace charging, domestic charging will be key to EV uptake. Vehicles are commonly at home overnight (19:00 to 08:00). Therefore, Level 1 charging would be adequate and practical.

However, given a significant take-up of EVs, smart metering/delay timers will be needed to ensure that vehicle charging takes place outside the hours of greatest demand for other needs (i.e. avoiding peak demand during evenings and early mornings); see **Figure 2**. In this way, although total demand for electricity would rise, the supply can be matched to the demand more closely. If provided with an 'override button' to facilitate immediate charging, this solution could overcome objections from potential EV users, as the public already accepts daytime/overnight electricity tariff structures, provided there is an opportunity to override.

Residential and workplace recharging points are shown to be technically capable of providing the majority of EV accessible passenger-km at a much lower cost than publicly available recharging solutions[11].

VEHICLE TO GRID

'Vehicle to grid', or V2G, is the term for the use of vehicle batteries to supply power back to the grid at times of peak demand. A large proportion of EVs could be connected during their periods of non-use (i.e. parked while at work) – this coincides with periods of significant demand for electricity. In effect, EVs would act as a distributed source of electricity which can be accessed to supplement the grid for short periods.

However, concerns have been expressed about the cost of achieving this[12]. The cost of supplying a unit of electricity from an EV is in the region of £0.09/kWh. This exceeds the current average marginal cost of electricity generation; therefore this challenges the feasibility of V2G operation. Electricity prices can, however, vary according to demand and generation mix, so under some [high-demand] circumstances, V2G back-up for the grid could be economically viable.

Figure 2: Great Britain Summer and Winter Daily Electricity Demand Profile in 2009 (excl. station demand); showing demand (GW) over 24 hours. (Source: National Grid)

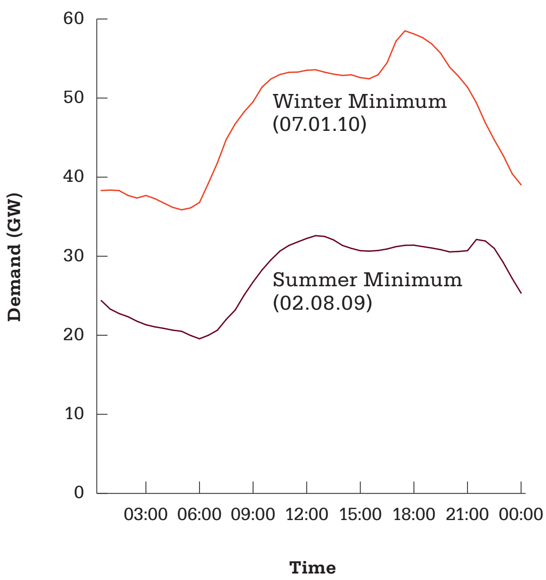


Table 2: Mayor of London's Draft Electric Vehicle Infrastructure Strategy

Charger location	Planned: Number (%)	Notes
Workplace	22,500 (88%)	Workplace parking spaces; largest employers
Off-street	2,500 (10%)	Train and tube station car parks; public car parks; retail car parks
On-street	500 (2%)	In 49 town centres; at potential EV households and workplaces with poor off-street parking

CONCLUSIONS

We are entering a period during which choices regarding EVs and their enabling infrastructure will have a significant impact on the long-term viability of EVs. The availability of appropriate charging facilities will be a vital part of this.

The Institution believes that battery swap is not a sustainable mainstream infrastructure option for charging EVs due to relatively high cost and the strong likelihood that developments in rapid plug-in charging will erode the time benefit it offers. However, Levels 1, 2 and 3 charging facilities all have a role to play within our future charging infrastructure, choice depending on a range of factors.

Domestic charging alone would take us a long way towards electrification of cars in the UK. We already have widespread (but not universal) infrastructure available for domestic Level 1 slow charging. This should use smart metering and delay timers to enable effective and efficient supply management; override switches that enable the immediate charging could be important in overcoming user reluctance (even if rarely used). Residential and workplace recharging points are shown to be technically capable of providing the majority of EV accessible passenger-km at a much lower cost than publicly available recharging solutions.

Public charge points can be provided in a controlled and planned manner. Emphasis should be placed on reaping the benefits offered by workplace charging, which can commonly use Level 1 slow charging; this should utilise smart metering and delay timers.

The Institution supports the approach taken by the Mayor of London[13] in planning for:

- 100,000 EVs on the capital's streets as soon as possible.
- Over 25,000 charging spaces (mostly Level 1 (slow) charging) in London's workplaces (see **Table 2**, opposite).
- At least 1,000 Greater London Authority fleet EVs by 2015.

A continued focus on fast charging and fast-chargers is nevertheless still needed, so that when charge times are reduced to about ten minutes (for an 80% charge), public charging points can start to play a significant role. This could be crucial in creating widespread acceptance by users, particularly in the context of journeys longer than or near to maximum vehicle range.

RECOMMENDATIONS

To help support and enable the widespread and timely uptake of EVs:

1. Government should play an active and central role in creating co-operation among local authorities, to ensure consistent EV infrastructure strategies are adopted while still meeting region and location specific needs.
2. Strategic planning authorities should prioritise the introduction of workplace Level 1 chargers, using smart metering and delay timers to help match supply to demand.
3. Manufacturers should work together to create and use consistent standards and protocols for charging and billing; this will be in their long-term interests, as interoperability will be an important factor in promoting user uptake.
4. Government and manufacturers should work together to fund and undertake research into reducing 'rapid charge' times; a target time of ten minutes should be set.

REFERENCES

1 The Fourth Carbon Budget; Reducing emissions through the 2020s; Committee on Climate Change; December 2010

2 Strategies for the uptake of electric vehicles and associated infrastructure implications; Element Energy for The Committee on Climate Change, Final Report; October 2009

3 Policy options for electric vehicle charging infrastructure in C40 cities; R. Philip & A. Wiederer; www.innovations.harvard.edu/cache/documents/11089/1108934.pdf

4 National Travel Survey 2009; DfT; July 2010

5 www.dft.gov.uk/pgr/statistics/datatablespublications/nts/; accessed on 29 September 2010

6 www.dft.gov.uk/pgr/statistics/datatablespublications/nts/; accessed on 29 September 2010

7 Strategies for the uptake of electric vehicles and associated infrastructure implications; Element Energy for The Committee on Climate Change, Final Report; October 2009

8 Armature induction charging of moving electric vehicle batteries; United States Patent 5821728

9 The CEO of Better Place, is quoted as having stated that the company's battery swapping stations would cost about $500,000 to build (www.businessinsider.com/the-cost-of-a-better-place-battery-swapping-station-500000-2009-4#ixzz11frwvcT2)

10 Strategies for the uptake of electric vehicles and associated infrastructure implications; Element Energy for The Committee on Climate Change, Final Report; October 2009

11 Strategies for the uptake of electric vehicles and associated infrastructure implications; Element Energy for The Committee on Climate Change, Final Report; October 2009

12 Strategies for the uptake of electric vehicles and associated infrastructure implications; Element Energy for The Committee on Climate Change, Final Report; October 2009

13 Mayor of London's Draft Electric Vehicle Infrastructure Strategy; www.london.gov.uk/electricvehicles/

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