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Ultra-Low-Emission Vehicle Infrastructure – What Can Be Done

Harold Dermott

September 2017

The Royal Automobile Club Foundation for Motoring Ltd is a transport policy and research organisation which explores the economic, mobility, safety and environmental issues relating to roads and their users. The Foundation publishes independent and authoritative research with which it promotes informed debate and advocates policy in the interest of the responsible motorist.

RAC Foundation
89–91 Pall Mall
London
SW1Y 5HS

Tel no: 020 7747 3445
www.racfoundation.org

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About the Author

Harold Dermott has spent over 35 years in the motor manufacturing industry, including 15 years running his own company.

He has project managed a major vehicle programme as well as creating and running the Business Development and Customer Care Departments for McLaren Automotive Ltd. Since launching HD&A Consultancy in 2011, he has worked exclusively in the EV charging infrastructure business.

His extensive involvement in every aspect of the installation and operation of all types of EV charge point for many years has enabled a clear understanding of both the commercial and customer requirements necessary for an effective charge point network.

Harold has a BEV and regularly uses public charge points.

Acknowledgements

The author would like to thank Steve Gooding, Director of the RAC Foundation, for identifying the need to associate the comments in this report with the Automated and Electric Vehicles Bill, thereby changing its focus and timing. Thanks also to Bhavin Makwana for co-ordinating this work and providing comments on earlier drafts.

Disclaimer

This report has been prepared for the RAC Foundation by Harold Dermott. Any errors or omissions are the author's sole responsibility. The report content reflects the views of the author and not necessarily those of the RAC Foundation.

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List of Abbreviations

AEVB	Automated and Electric Vehicle Bill
BEV	battery electric vehicle
CCS	Combined Charging System
CPN	charge point network
EV	electric vehicle, includes BEVs and PHEVs but excludes FCEVs
EVCH	electric vehicle charging hubs
FCEV	fuel cell electric vehicle
HDA	Harold Dermott & Associates
HRS	hydrogen refuelling site
ICE	internal combustion engine
LFR	large fuel retailer
MSA	motorway service area
MTB	Modern Transport Bill
NKL	Netherlands Knowledge Platform for Public Charging Infrastructure
OLEV	Office for Low Emission Vehicles
PHEV	plug-in hybrid electric vehicle
SOC	state of charge
ULEV	ultra-low-emission vehicle: emissions below 75 gCO2/km
V2G	vehicle-to-grid
V2X	vehicle-to-everything
VTAB	Vehicle Technology and Aviation Bill
WVTA	Whole Vehicle Type Approval

At the end of **June 2017, Plug-in hybrid vehicles (PHEVs)** accounted for **67,344 (63%)** of the total **106,846 electric vehicles (EVs)** registered in the UK

Even though **80%** of EV owners have access to **home charging** **93%** use the **public charge point network**

73% of public charge point use takes place at **local fast and slow chargers (3.6kW to 22kW)** with **27%** taking place at **rapid charge points (43kW to 50kW)**

Rapid charge points are **essential** for **Battery Electric Vehicles (BEVs) on long journeys** but are **irrelevant** for **PHEVs**

Rapid charge points should be **supported** by the installation of **fast** chargers to provide **a cost-effective solution** to the **problem** of **PHEVs** 'blocking' **BEVs**

The current **public network** is **unsuitable** for encouraging the next wave of EV customers. The Government must be prepared to **support EV charging hubs**, which are refuelling stations **specifically designed for EVs**

Public charge point **unreliability** is a problem with a **13%** national **failure rate** in June 2017

The public charge point network needs to be able to cope with the **significant increase** in average **battery capacity**. This will require **higher-capacity (100 kW+)** rapid charge points on trunk roads in order to **maintain acceptable charge times**

Within five years, ex-EV batteries are expected to become available in quantity, providing **cost-effective energy storage solutions.** **Smart charging, grid balancing** and **avoiding** the **high cost** of multiple charge point installations will all **require energy storage**

Foreword

The modest scale, and somewhat fragile state, of the UK electric car market is a sign that we are still at the very start of the journey towards a zero-emissions future for motoring – a prerequisite of continued enjoyment of the many benefits that driving has brought: access to jobs, education, the shops and other services.

If the pace of progress is to pick up, advances on several fronts will be needed to tackle the problems which are holding us back from deciding that an ultra-green car is for us:

- Retail – bringing the price of vehicles down and getting a wider variety of models into the showrooms.
- Range – reducing the risk that we'll run out of juice and be left stranded.
- Residuals – tackling worries about trade-in values, and specifically the cost and life expectancy of batteries.
- Recharging – still a surprisingly complicated business, particularly for households without access to off-street parking.

The first three in this list are vehicle-specific and fall predominantly to the automotive manufacturers to tackle. We're already seeing positive signs that the newest vehicles will match their petrol and diesel equivalents for range between refuelling stops, and provide model choices from superminis through to SUVs, reflecting the varied requirements that different lifestyles demand. But the fourth issue – ensuring adequate recharging capacity at the road side – lies predominantly in the public sphere.

Few of the nation's 30 million owners of petrol and diesel cars need to waste much time thinking about the process of refuelling: pull in to a garage – any garage – flip the cap, insert nozzle, fill, pay and away you go. Job done.

If only the same could be said about public recharging of plug-in electric vehicles. First, find your charge point - one that's in a convenient location, offering the right speed of charge and with the right connector. With luck, it will be in service, not already taken by someone else and you'll also have the right contract with the right provider to start charging.

To be fair, ministers recognise that this complexity could stall the sought after electric revolution. Hence the Automated and Electric Vehicles Bill announced in the June 2017 Queen's Speech will "provide for the installation of charging points for electric and hydrogen vehicles". But how?

To begin to answer that question, we commissioned Harold Dermott to explore how best the powers sought by the government could be used. We hope that his report will provide a set of useful pointers for national and local government as to what needs to happen, and what they need to do, if we are to accelerate smoothly and swiftly towards a cleaner, greener motoring future.

Steve Gooding
Director, RAC Foundation

Executive Summary

Battery electric vehicles (BEVs) were around at the dawn of motoring when they lost out to the internal combustion engine (ICE) but have enjoyed a renaissance over the last seven years. During the next decades their market share is forecast to rise dramatically, emphasised by the recently announced Government plan to ban the sales of new petrol and diesel vehicles from 2040. In order to operate on the roads, these vehicles require infrastructure – a charge point network (CPN).

The UK's CPN is already widespread and on the face of it the country is well provided for; a closer look, however, reveals problems in the present infrastructure. The current administration introduced proposed legislation in 2016 with the aim of keeping the CPN technologically abreast of the continual developments in the field of electric vehicles (EVs).

This paper has been written to review the current effectiveness of the CPN in the light of these advances in technology, and to evaluate the suitability of the proposed legislation for achieving the improvements in the CPN that will be needed. It makes the following proposals and observations:

- The CPN needs to be refined to match the type and location of charge points to EV owners' preferred charging patterns. Although nearly all EV owners use the CPN, 80% carry out most of their charging at home. The majority of CPN use is at local fast charge points in locations that the EV owners will in any case be visiting, such as shopping centres, hotels and leisure centres. The use of rapid charge points, which are installed predominantly on motorways and trunk roads, is essential if BEVs are to have the credibility to replace ICE vehicles on longer journeys.
- The different EV charging mechanisms need to be better understood by decision-makers to ensure that relevant charge points are installed. BEVs and plug-in hybrid electric vehicles (PHEVs) can share local charging, but have completely different requirements on long journeys. Rapid charge points, which are essential to the use of BEVs on long journeys, are irrelevant to PHEVs, which cannot take advantage of their capabilities. The Automated and Electric Vehicle Bill (AEVB) can therefore encourage better investment decisions by providing for the differing requirements of BEV and PHEV vehicles at motorway service areas (MSAs) and large fuel retailers (LFRs).
- The CPN needs to be able to cope with the significant increase expected to take place in BEV average battery capacity over the next few years. This will require higher-capacity (100 kW+) rapid charge points in order to maintain acceptable charge times. To avoid increased demand on the grid, these charge points should be supported by energy storage.
- Charge point unreliability (standing at 13% of them out of service) needs to be addressed if the network is to remain credible. The AEVB draft legislation would allow repair times to be legislated for (as already happens in the Nertherlands) to increase charge point availability.

- Home charging is likely to remain the main method of charging EVs. The AEVB draft legislation, which requires all new charge points to be smart, should be extended to home charge points, as this is where most of the energy transfer is likely to take place.
- Smart charging, grid balancing (matching the supply of energy with demand) and new charge point installations will all require energy storage. The cost of storage batteries is falling, and 1–2 megawatt (MW) batteries are now commercially available. Within five years, ex-EV batteries are expected to become available in quantity, providing cost-effective energy storage solutions.
- The existing grant system to support the CPN encourages quantity rather than quality. The current network is unattractive to use, and is unsuitable for encouraging the next wave of EV customers – people who will be making a vehicle choice rather than a lifestyle statement.
- The Netherlands appear to be European leaders in most of the issues discussed here, and NKL's Uniform Standards for Charge Points would appear to be a good starting point for UK-relevant regulations.
- Affordable BEVs with real-world ranges of around 200 miles are available now, and within three years most BEVs will offer ranges of 250 to 300 miles. Considering this in conjunction with improved rapid charging at MSAs and LFRs, it is clear that range anxiety is becoming a thing of thing of the past.
- The draft legislation in the AEVB is intended to address medium- and long-term CPN issues. However, the wording appears general enough to address also some important short-term problems highlighted in this paper.

1. Introduction

Battery electric vehicles (BEV) were first introduced to the UK at the end of the nineteenth century, at the same time as early internal combustion engine (ICE) vehicles. History relates that, given the technology and resources of the time, it was ICE vehicles that deposed the horse and became the default mode of personal land transport for the next 100 years. The modern renaissance of the BEV in the UK began in 2010, and since that time the UK government (via OLEV, the Office for Low Emission Vehicles) has stimulated the creation of an electric charge point network (CPN) to support these vehicles. Initially this was through their Plugged-in Places initiative, and subsequently through more specific grants for rapid charge points on motorways and trunk roads, as well as home charge points and workplace charge points.

The Society of Motor Manufacturers and Traders data shows that annual new electric car registrations in the UK have grown from 138 (a 0.007% market share) in 2010 to 36,907(a 1.4% market share) in 2016 (SMMT, 2017). The UK Government has previously aspired to 100% of new cars being ultra-low-emission vehicles (ULEVs) by 2040 (Knight, Kivinen & Fell, 2015), and in July

2017 this became Government policy. A report to the Committee on Climate Change in December 2013 (Element Energy, 2013) predicted that this would require an annual new vehicle market share of 16% (approximately 400,000 ULEVs) by 2020 and 60% by 2030. This would mean that the UK electric vehicle (EV) fleet could be about seven times larger four years from now if these goals are met.

To date, the UK public CPN, encouraged by government grants, has seen the installation of a number of electric charge points to charge both BEVs and PHEVs, leading to a UK total of 12,849 EV charging connectors on 6,913 devices in 4,476 locations (June 2017). This compares with 8,476 petrol stations in 2016 (UKPIA, 2017). However, these bare statistics can be misleading.

In late 2016, the Government introduced proposed legislation, with the intention of ensuring that the CPN was relevant to the continuing changes in technology. Initially this proposed legislation was included in the Modern Transport Bill (MTB), then the Vehicle Technology and Aviation Bill (VTAB) and finally in the Queen's Speech in June 2017, as the Automated and Electric Vehicles Bill (AEVB). All references to the proposed legislation in this paper will be to the AEVB.

The objective of this paper is to review the current effectiveness of the CPN, noting what must happen to ensure that the constant changes in EV technology and customer usage patterns can be reflected by equivalent improvements in the public charging network that supports them. It will also consider whether the proposed legislation in the AEVB can be used to achieve this.

Part 1 reviews the current status of the ULEV infrastructure. Part 2 suggests how the relevant proposed measures in the AEVB could be used to address some of the problems. Part 3 summarises the problems which are unlikely to be resolved by the AEVB, and how they might be addressed.

2. ULEV Infrastructure – the Background

There are several different types of ULEV available in the UK, but the most prominent over the last five years have been BEV and the PHEV. At the end of Q1 2017, the ULEV population of 94,293 vehicles licensed in the UK was divided PHEV 57.8%, BEV 42.1% and hydrogen-powered fuel cell vehicles (FCEVs) less than 0.1% (RAC Foundation, 2017).

One of the issues facing the increased usage of ULEVs is the ability to easily add energy to them, whether in the form of gas or electricity. The benchmark is inevitably that set by the universal petrol and diesel fuelling system developed over the last century. At petrol filling, stations energy is transferred to vehicles in a few minutes at reliable pumps situated in dry, well-lit areas – and, of course, there is a 100% expectation of receiving fuel.

Whilst this paper will therefore concentrate on the immediate issue of the much larger infrastructure needed to support BEVs and PHEVs, a brief overview of the infrastructure to support FCEVs is relevant.

2.1 Fuel cell electric vehicle refuelling infrastructure

FCEVs are powered by hydrogen gas stored at very high pressure (up to 700 bar, or *c.*10,000 psi) in a special tank in the vehicle. Fuelling stations therefore need to provide bulk storage of hydrogen gas which can be supplied to vehicles at this pressure with suitable safety precautions in place. Refuelling stations use hydrogen from steam reformation or use electricity to generate hydrogen from water by electrolysis. The FCEV then uses a fuel cell to convert the hydrogen back to electricity to drive the car.

Toyota Motors, a major supporter of and investor in FECVs, in their written evidence to the Business, Energy and Industrial Strategy Select Committee inquiry into Electric Vehicle, point out that it took them ten years to sell their first one million simple (not plug-in) hybrids, and that the length of time to develop a market for such new technologies should not be underestimated. Toyota's current plans are to increase their FCEV *global* production to 3,000 units by 2019 and then to 30,000 units in the early 2020s. They are also part of the UK H2Mobility programme, which projects about 65 hydrogen refuelling stations nationally by 2020 – a number that they feel would provide "basic national coverage" (Matysik & O'Keefe, 2017: 2).

As of mid-June 2017, there were 14 UK hydrogen refuelling points for FCEVs, of which three (21%) were out of service. There is just one refuelling north of Sheffield (Zap-Map, 2017a). This compares with a UK total of 12,849 EV charging connectors on 6,913 devices in 4,476 locations (June 2017), of which 13% were out of service (Zap-Map, 2017b). There were 8,476 petrol stations in the UK in 2016 (UKPIA, 2017).

2.2 BEV and PHEV charging infrastructure

Any review of the UK's EV charging infrastructure is only possible with an understanding of the basic technical issues involved in EV charging, and a good grasp of the benefits and disadvantages of each type of charge point. Simply considering the total number of charge points can lead to poor decisions being made.

Nomenclature and important background information

Rapid charging is defined as a charge rate greater than 22 kW; fast charging is defined as a charge rate of between 7 kW and 22 kW; slow charging is defined as a charge rate less than 7 kW (Zap-Map, 2017b). Of the 12,849 EV charging connectors in June 2017, 18% were rapid, 62% fast, and 20% slow (Zap-Map, 2017c). A 50 kW rapid charge point will typically transfer up to about 22 kWh of energy in 30 minutes, depending on the capacity, temperature and state of charge (SOC) of the battery being charged. The same amount of energy will be transferred by a 7 kW fast charge point in about three hours and a by 3.6 kW slow charge point in about six hours.

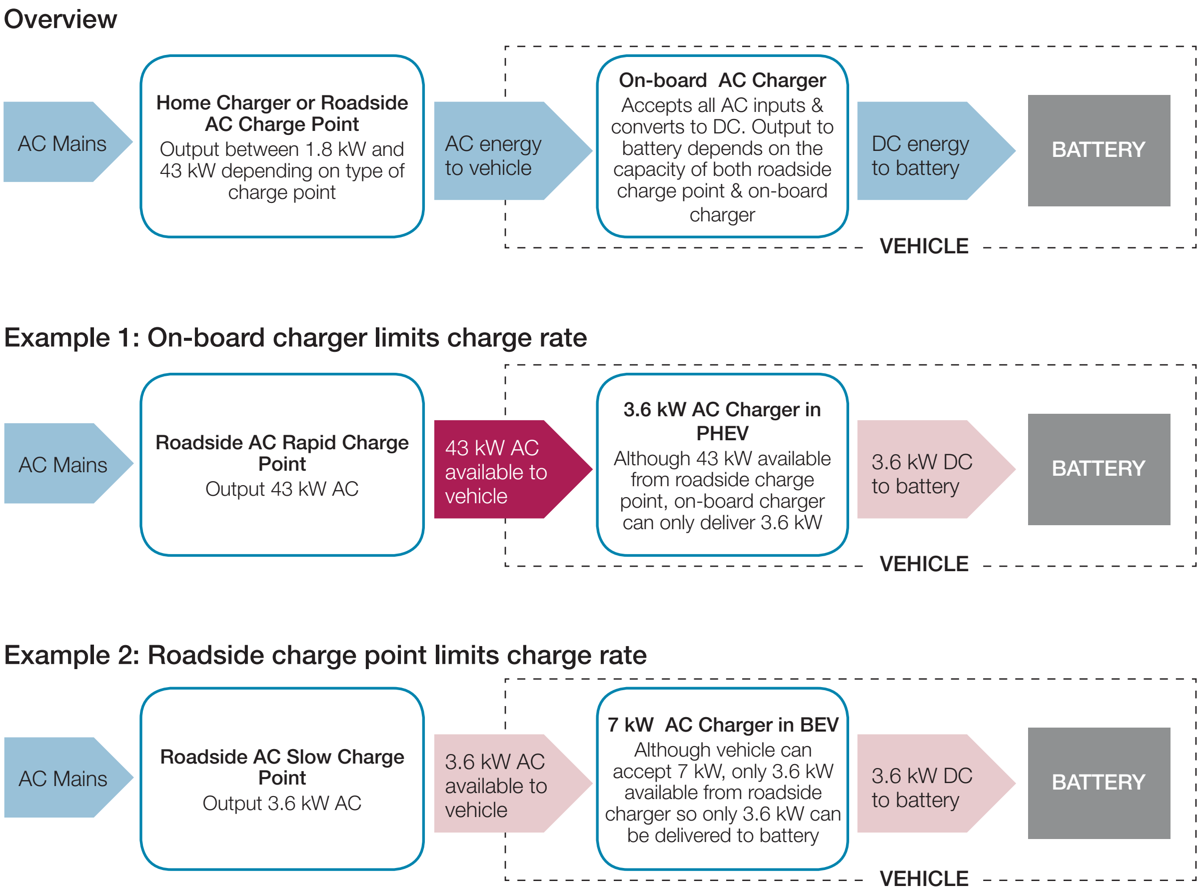
One of the key factors for a successful CPN is the ability to provide an attractive way for customers to spend their time whilst their vehicle is charging. This tends to fall into two categories: charging the car at locations where customers spend time for other purposes, which applies mainly to fast charging; and providing specific support services for customers whose primary reason for being at the location is to charge their vehicle, which applies mainly to rapid charging.

Types of electric vehicle charger

There are two types of EV charging process: AC (alternating current) and DC (direct current).

AC charging is carried out via an on-board device on the car, usually called 'the charger'. This on-board charger controls the entire charging process and also – just as importantly – may put a limit on the rate of charge, which maximum rate will vary from car to car. Figure 2.1 shows details of the AC charging process,

Figure 2.1: AC charging procedure for all BEVs and PHEVs (simplified)



Source: Author's own

The other type of EV charging process is DC charging, which bypasses the on-board AC charger to charge the battery directly. The charge is controlled by the roadside charge point, via the battery electronic management unit on the vehicle. DC charging is used exclusively for rapid charging; nearly all BEVs can accept DC rapid charging.

Table 2.1: Public charging capability of the most popular BEVs and PHEVs

			On Board		Public Charging	
Make	**Model**	**Type**	**Charge Sockets**	**Charger**	**1st Choice**	**2nd Choice**
Audi	A3 e-tron	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
BMW	i3	BEV	CCS,Type 2	7 kW	50 kW CCS DC	7 kW AC
BMW	i8	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
BMW	330e	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
BMW	225xe	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
BYD	e6	BEV	Type 2	30 kW	43kW AC	22 kW AC
Mercedes	C350e	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
Mitsubishi	Outlander PHEV	PHEV	CHAdeMO, Type 1	3.6 kW	CHAdeMO 20 kW DC	3.6 kW AC
Nissan	e-NV200	BEV	CHAdeMO, Type 1	3.6 kW, 6.6 kW option	CHAdeMO 50 kW DC	7 kW AC
Nissan	Leaf	BEV	CHAdeMO, Type 1	3.6 kW, 6.6 kW option	CHAdeMO 50 kW DC	7 kW AC
Porsche	Panamera S E-Hybrid	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
Renault	Kangoo ZE (to 2017)	BEV	Type 1	3.6 kW	3.6 kW AC	N/A
Renault	Kangoo ZE (from 2017)	BEV	Type 2	7 kW	7 kW AC	3.6 kW AC
Renault	Zoe	BEV	Type 2	22 kW, 43 kW option	43 kW AC/22 kW AC	22 kW AC/7 kW AC
Tesla	Model S	BEV	Special Type 2	11 kW or 22 kW	Supercharger 135 kW	CHAdeMO converter
Tesla	Model X	BEV	Special Type 2	11 kW or 22 kW	Supercharger 135 kW	CHAdeMO converter
Toyota	Prius Plug-In	PHEV	Type 1	3.6 kW	3.6 kW AC	N/A
Vauxhall	Ampera	PHEV	Type 1	3.6 kW	3.6 kW AC	N/A
Volvo	V60 Plug-in Hybrid	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
Volvo	XC90 T8 Twin Engine	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
VW	Golf GTE	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A
VW	Passat GTE	PHEV	Type 2	3.6 kW	3.6 kW AC	N/A

Source: Author's own
Note: N/A: not available

Every BEV or PHEV on the road will accept an AC charge. *Only BEVs can accept 50 kW DC rapid charging.* (The Mitsubishi Outlander PHEV has a rapid charging socket, but charges at only 20 kW, not 50 kW, on this socket.)

It will be seen from Table 2.1, which lists popular EVs and shows their public charging capability, that *no PHEV currently on sale in the UK can accept an AC charge greater than 3.6 kW*. Therefore it is critically important when considering the UK public charging network to recognise that slow and fast AC chargers are the *only* relevant chargers for PHEVs.

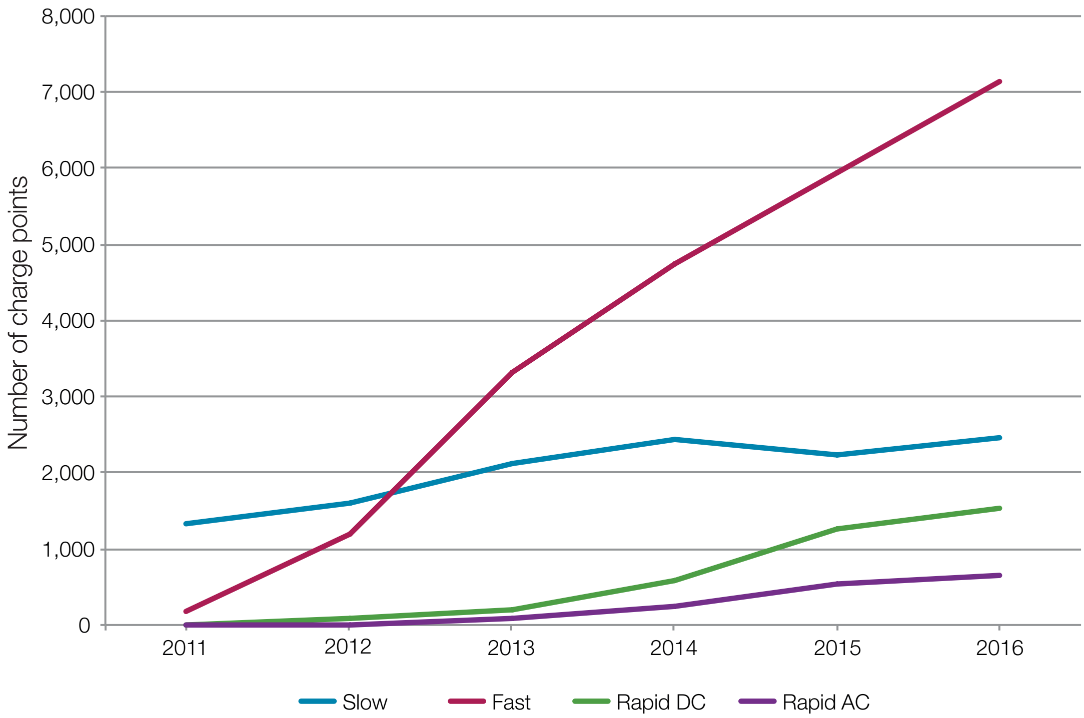
At the end of June 2017, PHEVs accounted for 63% (67,344) of the total 106,846 EVs registered (SMMT, 2017). At that time, there were 7,980 fast connectors and 2,557 slow connectors in the UK public charging network (Zap-Map, 2017a).

2.3 The demand for UK electric vehicle public charging

The proportion of UK EV owners with the ability to charge at home now stands at 80% (Zap-Map, 2016) this is the cheapest and most convenient way to recharge any EV. However, people do not always have access to off-street parking – in outer London, 35% of households have no access to off-street parking to charge an EV, and in inner London this rises to 63% (TfL, 2012). The ability to charge an EV in cities, particularly London, is essential as a potential solution (or large part of the overall solution) to urban area air quality problems.

In addition to home charging, Figure 2.2 shows the growth over the last several years in numbers of the four types of EV public charge points in the UK.

Figure 2.2: Number of UK electric vehicle public charge points by type, 2011–16



Source: ZapMap (2017b) and author's calculations

There is limited and often apparently conflicting information on how EV owners use the current public charging network. For example, the general false assumption is that EV owners refill their cars as if they were petrol/diesel cars, by running the 'tank' low then filling it up. The evidence is to the contrary: a survey in 2015 found that only 24% let their battery fall below 20% SOC before charging (Zap-Map, 2015).

A later 2016 survey, summarised in Table 2.2, examined how EV owners used the CPN:

Table 2.2: Public charging usage and dwell times by location

		Usage		Typical energy transfer		
Location	**Type**	**AC (%)**	**Overall public (%)**	**Typical output (kW)**	**Typical dwell time (h)**	**Max energy transfer (kWh)**
Home[a] (for reference only)	AC			7	10	70
Work[b] (for reference only)	AC			7	8	56
Public charge points - DC						
Motorway service area	DC		**27%**	50	0.5	25
Trunk road service station	DC			50	0.5	25
Other location	DC			50	0.5	25
Public charge points - AC						
Public car park	AC	20%	**73%**	7	1	7
Retail car park	AC	19%		7	2	14
Local authority car park	AC	17%		7	1	7
Dealership forecourt	AC	11%		7	1	7
On-street	AC	10%		7	2	14
Park-and-ride	AC	7%		7	3	21
EV charging hub	AC	6%		7	2	14
Hotel / other accommodation	AC	6%		7	10	70
Leisure centre	AC	2%		7	1	7
Other	AC	3%		7	1	7

Source: ZapMap (2016) and author's work
Note: (a) 81% of EV users have access to a home charger.
(b) Only 25% of EV users can charge at work.
AC charge point usage shown will reflect available charge point locations as much as desired locations to charge

These 2016 survey (Zap-Map, 2016) results indicate that EV owners 'graze' (charge whilst being at the location primarily for another purpose) at available charge points which suit their existing routine and existing 'dwell times'. This means that car parks for shopping, using a gym or staying at a hotel are ideal locations for 7 kW fast chargers.

The presence of EV charging facilities is a key factor for EV users in deciding where to park. The 2015 survey found that 95% of all those questioned select a public parking location based on whether an EV charging point is available at that location (Zap-Map, 2015).

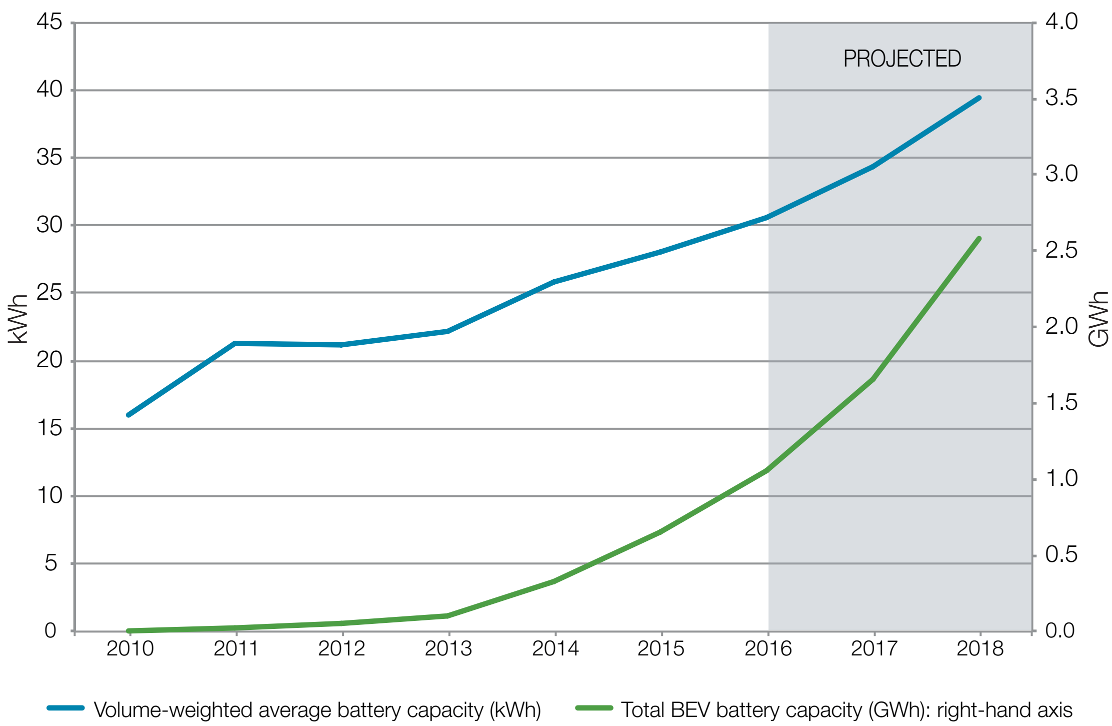
It is important to recognise that using an EV will require a different 'refuelling' provision from that for an ICE car, just as the ICE car did from the horse that preceded it. Installing charge points at petrol stations is not a solution to infrastructure provision.

2.4 The continuing improvements in battery technology

BEV battery technology has improved significantly over the last few years, which has resulted in the availability of batteries that, while approximately the same weight and size as their predecessors, have a much larger capacity. Some of these are already available – for example the Renault ZOE now has a 41 kilowatt-hour (kWh) battery fitted in the same space which held the 22 kWh battery of the earlier car, and it is only 15 kg heavier. This provides a 68% increase in range in the NEDC (New European Driving Cycle) driving range – a somewhat optimistic and theoretical measure but useful principally for making fair comparisons – from 149 miles to 250 miles).

The average battery capacity of the UK BEV fleet will continue to increase, although it is not clear how this will affect the demand for public charging. Figure 2.3 shows historic and projected capacities, in terms of per-battery capacity and the total across all batteries.

Figure 2.3: Average historical and projected BEV battery capacity and total BEV fleet battery capacity



Volume-weighted average battery capacity = (vol car 1 x car 1 battery capacity.) + (vol car 2 x car 2 battery capacity.) + … / total number of cars

Source: RAC Foundation (2017), manufacturer battery data and author's work

It is likely that the habit of charging at home will persist for the majority of EV owners who have that facility. It is usually the most convenient and also the cheapest way of charging any EV. The standard 7 kW home charger adds approximately 70 kWh in ten hours, which is still relevant to batteries of capacity up to about 100 kWh. In practice, overnight charging has a window of 12 hours or more, and will normally begin from 20% SOC or above. There is also no reason to believe that the current habit of grazing at fast chargers, in locations where EV users already have a dwell time (the time spent at the charge point for the purpose of charging) for other purposes (see Table 2.2), will change.

What may change, though, is the demand for rapid charging on motorways and trunk roads. It is not acceptable to BEV users that the dwell time increases with the advent of larger batteries, as it is a component of the total journey time.

To put this in context, consider a BEV with a 24 kWh battery and a consumption of 4 miles per kWh (m/kWh) at 50 mph average motorway speed. The battery will reach a SOC of 20% after about 75 miles, which would therefore be the target distance for recharging. A 120 mile journey would take therefore take: 2 hours 24 minutes' driving plus a rapid charge of say 30 min (20% to about 75% charge at 50 kW nominal), a total of 2 hours 54 minutes, of which the charge time represents 17% of the journey time. For business purposes, this is debilitating.

With a 60 kWh battery, which would require a larger and heavier vehicle, with an assumed consumption of 3.5 m/kWh and a 60 mph average motorway speed, the same journey could be carried out without charging in a time of two hours, a significant saving of nearly an hour on the older technology. However, the car would either require a charge at the destination, or a rapid charge on the return journey. In this regime, 50 kW charging would not be seen as rapid, as it would take about an hour to charge from 20% to 75%, which is a very long time to spend at a garage or even a motorway service area (MSA). It is important to note that high-capacity DC charging is non-linear on many BEVs, as the charge rate decreases with time to protect the battery from overheating. More advanced batteries have better cooling, which will allow higher charge rates.

Thus, as the average battery capacity of the UK BEV fleet increases over the next three to five years, the public charging options become:

1. longer charges at existing 50 kW rapid chargers, which is likely to lead to queuing;
2. installation of higher-capacity rapid chargers (100 kW or 120 kW) to approximately maintain current charge times – this will highlight any site electrical capacity problems;
3. destination-based fast charging, in particular workplace charging, so that business drivers can charge on arrival where they have a minimum natural dwell time of one to two hours – this may lead also to the development of a new breed of 20 to 25 kW DC chargers for visitor parking spaces.

However, the bulk of the recharging of the cars in these examples is likely to continue to occur at home.

Connector types

There are three different types of connector. (CHAdeMO, Combined Charging System (CCS) and Type 2 AC) to be found on rapid charge points on the CPN and it is important for BEV owners to understand which type fits their vehicle

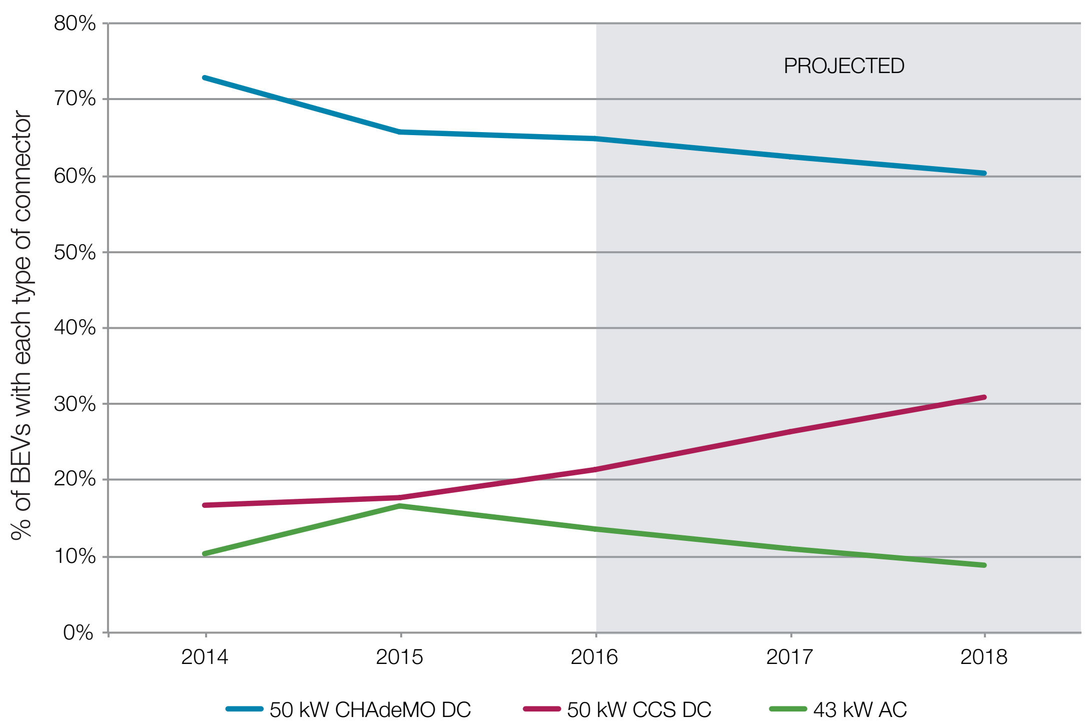
The 50 kW CHAdeMO (DC charging) connector is of Japanese origin and is fitted to cars such as the Nissan Leaf and Mitsubishi Outlander. A separate connector for AC charging is required on these vehicles.

The 50 kW CCS (DC charging) connector is of European origin and is used by all European-designed vehicles which have rapid charging capability. The CCS connector includes a Type 2 AC connector, so only a single charging port is required on the vehicle for both DC and AC charging.

The 43 kW Type 2 (AC charging) connector can only be used at full capacity on the Renault ZOE. Total ZOE sales are 14% of BEV cars registered in the UK at the end of 2016, but the 43 kW charging option on the ZOE has only been an option (as a £750 extra) since mid-2015. Despite this, 37% of rapid charging outlets are 43 kW AC (Zap-Map, 2017b). The new ZOE, due in 2020, is predicted to have a CCS connector for rapid charging (Kane, 2016).

The demand for each type of connector provided by rapid charge points in the CPN is defined by the number of BEVs on the road fitted with each type of connector. Figure 2.4 shows this from 2014 to 2016 and projections for 2017 and 2018.

Figure 2.4: Demand for each type of rapid charge point connector, UK-registered BEVs



Source: RAC Foundation (2017) and author's work

It is also worth noting that almost all rapid charger points currently installed, even when fitted with multiple connectors, can deliver only 50 kW through one connector at one time. If a second vehicle arrives, either it must wait until the first vehicle has finished (the case at nearly all charge points) or it can connect immediately, but the charge point downrates to 25 kW per connector, which nearly doubles the charge time and therefore largely negates the whole point of rapid charging.

All public fast chargers have Type 2 AC connectors. Public slow chargers can have Type 2 connectors, J1772 connectors, Commando or even 13 amp three-pin domestic sockets.

There is no case for continued installation of public slow charging, particularly with the increase of average battery capacity over the next few years. All new AC fast public chargers in the UK should be standardised at 7 kW capacity and Type 2 connector as Figure 2.1 and Table 2.1 shows that the majority of EVs on the road are unable to charge at a faster rate.

Private chargers for specific purposes with occasional public access (for example at workplaces or campsites) could retain their existing slow chargers. Slow charging may also be relevant for overnight street charging for EV owners in cities without off-street parking. An interesting initiative using lamp posts as a source of energy is currently being trialled in London and other cities (Edwards, 2015).

2.5 Charge point reliability

Public EV charging in the UK has existed only since 2011, and is therefore in its infancy. Like the EVs themselves, these early charge points may be considered as 'market seeding', making early products available to stimulate the dynamics of the market. However, following further major investment by car companies and global government support, the EV vehicle market can now be considered to be moving out of this phase, and it is important that charge points do as well.

Unlike the EVs which they charge, these early charge points are not built to any international standard, neither are they required to be tested for performance or conformity of production – they are simply self-certified by the installers.

In reply to a query for this report, Zap-Map stated "At the device level (rather than connector or location level), the percentage out of service is 13% – as of June 2017." As the number of devices shown at the time was 6,913 (Zap-Map. 2017b), this represents about 900 charge points out of service. This compares with the 99% availability expected by the Dutch system (NKL Nederland, 2017a). Consequently, in addition to limited range, current BEV drivers must always plan a back-up charge point when on a journey, in case the preferred charge point is not working. This unacceptable situation must change, in the same way that EVs are changing with improved technology, as it risks becoming a major disincentive to purchase an EV.

2.6 Funding charge point installation

Most information on the business models for EV charger installation is out of date (dealing with the period prior to 2015) and US-based (Agenbroad & Holland, 2014).

Indicative prices for the installation of a 50 kW rapid DC charge point are *c.* £50,000, and for a 7 kW fast charge point the figure is *c.* £4,000, depending on the work required at the site (DfT, 2016).

In addition there are operating costs, including for example: electricity, site rental, planned maintenance, emergency maintenance, 24-hour customer support and insurance.

The only income sources are from the operation of the charge point, which may include profit from the sale of electricity and a fixed connection fee for each charge. With a constant comparison to the cost of home charging being made by users, there are practical limits to the fees that can be charged to make the investment worthwhile.

The installation and operation of a public charge point, particularly a rapid charge point, therefore requires investors prepared to accept a moderate risk and only a long-term return on their investment. Given the level of investment in charge points to date, the Government clearly accepts that new technology requires support from public funds until it becomes self-sustaining; that point has not yet been reached for EV infrastructure.

2.7 The effect of electric vehicle charging on electricity demand and grid management

The effect on electricity demand and grid management of charging EVs is a complex and substantial subject, and can only be discussed superficially here.

With 80% of EV owners having access to home chargers, the bulk of energy transfer from the grid to EVs can be expected to take place at home overnight, which is also the period of lowest grid demand. Utility companies can promote night-time charging with tariffs that encourage EV users to charge at specific times, as on-board timers already fitted to most EVs can take advantage of this kind of time-differentiated tariff.

These sort of demand-side management measures are exactly what grids need to cope with the coming influx of EVs, and the lesson is being applied elsewhere in the developed world. Forward-thinking utility companies are beginning to offer financial incentives for EV users to charge their vehicles during off-peak overnight hours, and advanced EV charging hubs (EVCHs) are integrating local solar power, energy storage and dynamic pricing to manage EV demand on the grid (Lo, 2016).

For example, in Japan, investing heavily in battery storage and smart meters, providing subsidies for building energy management systems, and full deregulation of the energy market has amounted to “a remarkable investment in demand-side management in a short period”, according to an October 2014 report by Bloomberg New Energy Finance (2014: 1).

However, grazing at fast chargers – and particularly demand for rapid charging – will take place outside these off-peak times, with peaks for rapid charging occurring at the morning and evening rush hours.[1]

The UK is obliged to produce 15% of overall energy from renewables by 2020, this overall percentage breaking down into 30% of electrical energy and 10% of transport energy, but it is some way from meeting this target (Houses of Commons Select Committee on Energy and Climate Change, 2016).

The UK, like all major economies, has an electrical infrastructure that is based largely on twentieth century technology and equipment, and it is important to look to twenty-first century solutions to these new problems.

Such solutions for EV charging, particularly rapid charging, are likely to include energy storage. Charge could be put into this energy storage in a variety of ways – for example from the grid at times of off-peak load, or partly/wholly by solar panels. The energy stored could then be used to charge or partially charge EVs at peak times (the balance being drawn from the grid), thus aiding grid management. The practicality of these options is enhanced by the commercial availability, already, of EV rapid charge points with battery storage.

The EV industry itself is in a perfect position to be part of the solution to the increased demand for electricity caused by EVs themselves: owing to the very high energy demands in vehicles, EV vehicle batteries are expected to require replacement when their capacity has reduced to 75% of new, which in the UK climate is not anticipated to be within the eight-year warranty given by nearly all EV manufacturers. However, these 75% capacity ex-EV batteries would be ideal for energy storage (Van de Vegte, 2015). From about 2020, ex-EV batteries can be expected to become available in increasing volume for energy storage, both at home chargers and at public charge points.

In addition, the UK fleet of BEVs at the end of 2016 had a combined energy capacity of just over 1 GWh (see Figure 2.2). Data on existing and projected BEVs in the UK market suggests that this could rise to 2.5 gigawatt-hours (GWh) by 2018. For reference, UK total electricity demand is approximately one terawatt-hour (TWh) per day (BEIS, 2017). Using smart, bi-directional charge points, and with changes to EV on-board charging systems, this has the potential to release some of this stored energy back into the grid (vehicle-to-grid: V2G) or storage (vehicle-to-everything: V2X) at some time in the future. *It is important that the correct charge point equipment is being designed, built and installed today, if this technology is to prove viable.*

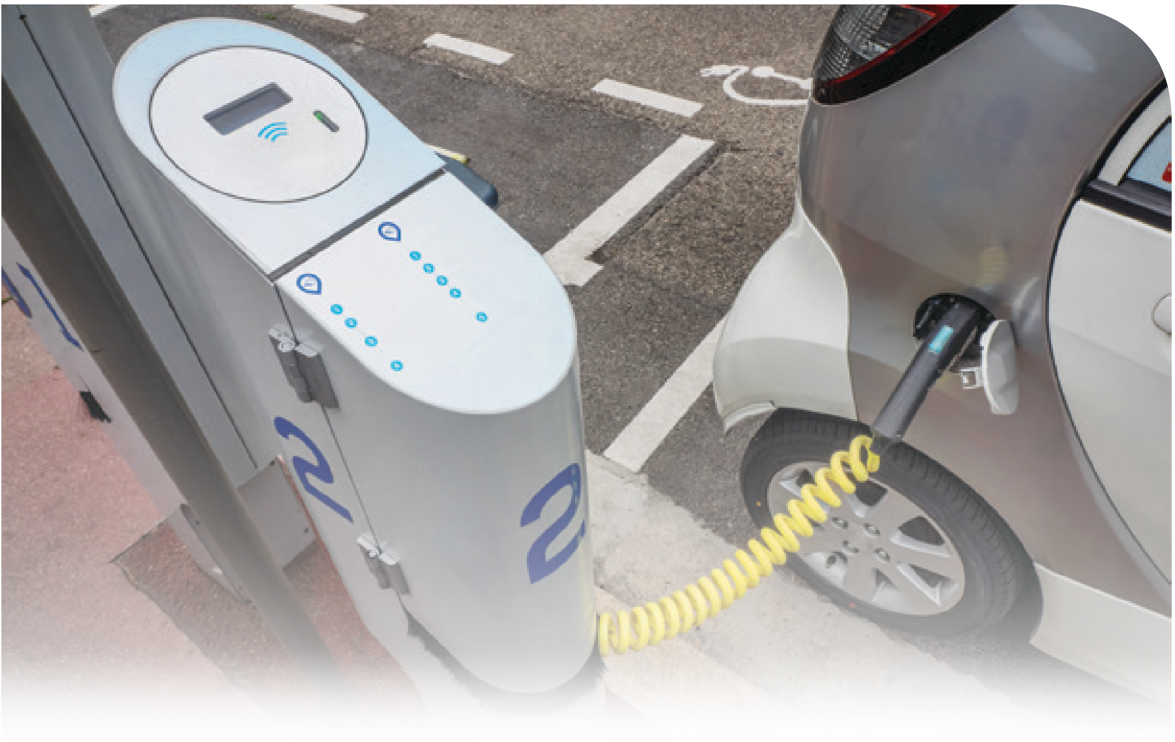
The Tesla global Supercharger network provides an example of what is possible. In April 2017 it had 830 sites in 31 countries with a total of 5,400 connectors (Golson, 2017). Each connector in a stall delivers 135 kW if used singly, or 67.5 kW if both connectors in a stall are used, thus the global network has a total capacity of 364.5 megawatts (MW). In the UK, which has a total of 40 Supercharger sites and 219 connectors (Zap-Map, 2017b), the total capacity would be 14.8 MW. Moreover, the UK Supercharger network is currently being

1 HDA knowledge from managing and operating EV charger installations

expanded to 54 sites. On 9 June 2017, Elon Musk, CEO of Tesla, stated “All Superchargers are being converted to solar/battery power. Over time, almost all will disconnect from the electricity grid” (Business Insider, 2017). Tesla is also engaged in the manufacture and sale of energy storage and solar panels, as well as BEVs and the design and installation of their Supercharger network.

Whilst these are ambitious targets for Tesla, the world needs such ambitious targets if it is to transfer completely from ICE vehicles to ULEVs within the next 20 to 25 years.

3. ULEV Infrastructure – The Relevance of The Automated and Electric Vehicles Bill



The Vehicle Technology and Aviation Bill (VTAB) was going through Parliament when the 8 June 2017 election was called. The Queen's Speech on 21 June 2017 announced the Automated and Electric Vehicles Bill, which contains the ULEV legislation originally proposed in the VTAB (VTAB, 2017). This paper will use the abbreviation AEVB to imply both. The main proposed legislation (PL) in the AEVB covers:

- **PL1**: provision of public charging points at large fuel retailers (LFRs) and MSAs;
- **PL2**: a requirement on public charging point operators to provide and share data to assist with ease of access and payment, including prescribed requirements for charge points and connecting components;

- **PL3**: smart charging, and the fact that it will necessitate the introduction of technical regulations for charge points to be accessed remotely by approved third parties – for example for the purpose of grid levelling; additionally, charge points and EVs must be able to discharge as well as charge vehicles.

How can these provisions best be used?

3.1 PL1: Provision of public charging points at large fuel retailers and motorway service areas

MSAs are already well advanced in the provision of charge points. In December 2016, the Department for Transport stated: “Out of the 129 MSAs situated in the UK, only seven (5%) are not equipped with at least one rapid charge point” (DfT, 2016). This document also points out that all these charge points are operated by the same company.

There are three challenges for improving EV charging at MSAs and LFRs:

1. **Type of rapid charge point**
   Rapid charging is relevant only to BEVs. The AEVB should specify only ‘double DC’ (CHAdeMO & CCS) DC rapid charge points at these locations. This will match type of connector to demand, as well as helping to offset the costs of the additional fast charge points.

2. **Preventing PHEVs from blocking BEVs from using the rapid chargers**
   Currently, when a PHEV arrives at an MSA, the only connector on the site that will fit the charging socket on the car is the 43 kW AC connector on the rapid charge point. Since the on-board charger is only 3.6 kW, this vehicle will take up to two hours to top up a typical 7–10 kWh PHEV battery. *No BEV will be able to charge during this time, as the use of one connector on the rapid blocks all others*. The solution to this is to legislate for multiple (a minimum of three) 7 kW AC fast charge points to be installed at MSAs and LFRs with each rapid charge point. This would mean that all PHEVs can charge at their highest capacity without blocking the rapid charge point, and BEVs can use the rapid charger. This is a highly cost-effective solution to providing relevant charging resources to ULEVs at MSAs and LFRs, by matching supply to demand.

3. **Electrical supply**
   Many MSAs are near the limit of their electrical supply, and PL3 is unlikely to assist with this. Additional rapid chargers will require additional electrical supply, or (the better long-term solution) battery storage buffering, adding to costs compared with the original operator. For reference, Tesla (amongst others) now has high-capacity battery storage commercially available: 2 MWh is being installed at a new development in Nottingham (Pratt, 2017). The AEVB should encourage energy storage at these sites by offering improved grants for installations which incorporate energy storage.

There is an additional issue at LFRs: the provision of an attractive place for customers to spend time whilst their vehicle is charging – a period of a minimum of half an hour, and possibly up to an hour if the rapid charger is occupied on arrival. Spending an hour wandering around the petrol pumps or in the shop with nowhere to sit is unlikely to be appealing to EV users.

3.2 PL2: A requirement on public charging point operators to provide and share data

The requirement for charge point operators to take the necessary steps to co-operate on method of payment, sharing facilities and sharing information is logical, and is likely to result in a more cohesive national charging network, whilst at the same time allowing competition between individual operators.

The AEVB also requires operators to provide information on whether charging points are in working order. To achieve this, fault data generated by the charge point must be 100% accurate or, as is the case now, customers will not trust that a charge point is actually available. Therefore charge points must be equipped with sufficient and relevant sensors to detect *all* failure modes. Most existing rapid chargers – and the newer fast chargers – already supply fault information, *but the quality of current data needs enhancing, as no current so-called 'live map' of charge points is accurate.*

In the short term, this fault information could also be used by the AEVB to specify maximum time of repair, which has the potential to significantly improve availability pending a longer-term solution (See Part 3, subsection 'Improving charge point reliability'). The AEVB enforcement section could also cover fines on a sliding scale for failure to repair chargers in a timely fashion. EV user experience is such that repair times are measured in days and weeks rather than hours and days; this if far behind the Dutch requirement of repairs within 24 hours (NKL Nederland, 2017a).

3.3 PL3: Smart charging and technical regulations for charge points

The AEVB requirement ensuring that the ability for smart charging is built into all new AC and DC charge points in the CPN appears to a very valuable target, but the following points need to be considered to make it effective.

Since the majority of energy transfer to EVs appears to be overnight via home charging, to achieve its objective, the AEVB must clearly include home charge points in this legislation, and make it a requirement of the current OLEV Electric Vehicle Homecharge Scheme that domestic charge points be bi-directional (i.e. allow discharge of electricity from the EV into the grid).

For AC smart charging to work, the on-board AC charger in every BEV (where most of the energy will reside) and PHEV must be bi-directional (Wang et al., 2016), which may to add to the vehicle price. In addition it is likely that the discharge rate, like the charge rate, will be limited to 3.6 kW or 7 kW for the vast majority of EVs.

This low discharge rate means that large transfers of energy to the grid (i.e. V2G) will be too slow to be significant, but they would be useful for recharging home or aggregated energy storage batteries (i.e. V2X). This stored energy would then carry out the V2G transfer at a time which would suit the grid. Storage would therefore appear essential for grid balancing using the EV fleet, in order to unlink the time when most energy would be available from the EV fleet (overnight) from the period when demand is high (during the daytime).

The ability to use discharge during a DC rapid charge would appear limited. The idea of being able to charge in less than 30 minutes on a long journey is an important concept for supporting BEV sales. Random reductions in the rate of charge to reduce the load on the national grid whilst charging at a rapid charge point would destroy the whole purpose of rapid charging. Without a reliable rapid charge point network, the sales of new larger-battery BEVs would be more difficult. Energy storage, not smart charging, is the answer to the issue of grid management for rapid charge points.

3.4 Experience in other countries

The Netherlands appear to be European leaders in most of the issues discussed here. The Netherlands Knowledge Platform for Public Charging Infrastructure (NKL) organisation plays a key part in this. In their own words:

> "NKL is the platform where government, knowledge institutions and companies come together to achieve affordable public charging. We stimulate development in the public charging sector, facilitate innovative projects, support various initiatives and ensure the exchange of knowledge. In the process, we strengthen the position of the Netherlands in the public charging sector." (NKL Nederland, 2017b).

Just as the German TÜV, which is a testing and certification agency, has a branch in the UK, so could NKL in their area of expertise. As an organisation which has been instrumental in making the Netherlands' EV infrastructure more advanced than that of the UK, they have the potential to quickly help the UK maximise the benefit from the changes proposed in the AEVB.

NKL's *Uniform Standards for Charge Points* would also appear to be a good starting point for a set of UK-relevant regulations. These standards already include protocols for exchanging information and preparing for smart meters of the sort that the AEVB requires (NKL Nederland, 2017a).

The Netherlands are also already carrying out countrywide testing of smart charging to match EV charging times to peaks in sun and wind generation, and are also looking to the EV fleet to act as storage for solar generation (Lambert, 2016). This is considerably in advance of the small-scale trials taking place in the UK. Using this knowledge and technology has the potential to reduce the time taken for the measures in the AEVB to become effective.

However, whilst the Netherlands appears to give clear support at all levels on an extraordinary range of EV support projects (Netherlands Enterprise Agency, 2016), the effectiveness and success of these would need to be confirmed, as the relevant projects do not appear to have been concluded to the stage at which reports are issued.

4. ULEV Infrastructure – Looking Beyond the Automated and Electric Vehicles Bill

4.1 Hydrogen refuelling infrastructure

Since hydrogen vehicles fill up with hydrogen in a similar manner to conventionally fuelled vehicles, with a similar refilling time of five minutes to eight minutes, consumers adopting this technology would not have to change their refuelling habits. Hydrogen refuelling points can also be integrated into normal fuel dispensing points and the current design and function of forecourts. They will also fit with the current business models for the use of space, and facilities at fuel retail outlets (House of Commons Public Bill Committee, 2017).

Hydrogen fuelling can offer grid-balancing services – a seasonal energy storage solution; this is possible because the time at which the hydrogen is generated can in theory be set to suit the grid, rather than being subject to demand, and the demand for power can thus be unlinked from the vehicle use (House of Commons Public Bill Committee, 2017).

These appear to be significant advantages, but there are problems, not least among which is the size and cost of the equipment for generating, storing and dispensing hydrogen on-site. Element Energy's *Installing Accessible Hydrogen Refuelling Stations: A best practice guide*, written on behalf of the London Hydrogen Network Expansion project, states that "Bottles of compressed hydrogen offer insufficient storage capacity for most hydrogen refuelling sites. Vertical tanks around 20 m high are being installed in a number of refuelling sites in Germany. These are preferred over tubes when space is at a premium as they offer a lower footprint solution" (Element Energy, 2015: 8). The current cost of installing hydrogen refuelling stations is very high: no UK data could be found, but a report by the US National Renewable Energy Laboratory in 2013 estimated costs based on the size of the station. For early stations capable of delivery of 160 kg of hydrogen per day (kg/d), which is the size of refuelling station currently being installed in the UK, the capital cost was estimated at US$2.65 million (or US$16,570 per kg/d). As demand increased, a 450 kg/d station would cost US$2.8 million (or US$6,222 per kg/d). By way of comparison, a rapid charge point costs approximately £50,000. In addition, FCEV prices remain very high for the two types of FCEVs available in the UK in June 2017 (£55,000 to £66,000). These FCEVs have ranges of about 300 miles, which is similar to PHEVs available now, and also comparable to the new generation of BEVs which will start to be available within the next year. On all these vehicles, range anxiety should no longer be a concern.

The planned H2Mobility programme, which projects about 65 hydrogen refuelling stations nationally by 2020, to provide "basic national coverage" (Matysik & O'Keefe, 2017: 2) would appear sensible, but the take-up of FCEVs should continue to be monitored to ensure that the hydrogen refuelling network supports the demand for these vehicles.

4.2 UK public charge point network – practical problems

Away from the statistics, the reality is that the UK public CPN is not attractive to use. Apart from an unacceptably high rate of charge points that do not work (13% as of June 2017), the network consists of:

- charge points that are completely unprotected from the weather;
- charge points that are poorly lit, often in corners of car parks;
- many badly designed rapid charge points incorporating poor cable management, resulting in dirty charge cables (and therefore dirty clothes) and connectors lying on the ground or in puddles (further reducing availability).

There are further problems, too:

- All charge points under 43 kW require a loose charging cable to be carried in the car. Poorly installed and badly located chargers result in dirty cables needing to be put back into the car.
- It is quite common for EV charging bays to be used as parking by ICE vehicles, resulting in EV owners being unable to charge because they cannot access the charge point.
- Some locations, even in town car parks, are quite remote, which could give rise to safety problems, particularly for the lone driver seeking to use them at night. Unlike most petrol filling stations, there is no attendant.

If this is the refuelling network intended to encourage new car buyers to choose an EV rather than another petrol or diesel car, then the user experience *must* be improved.

User experience is something that is normally resolved by competition, not by legislation. However, with EV volumes not yet sufficient to guarantee a reasonable return to operators, and if the Government persists in setting only simple numerical targets for the number of charge points installed, the public charging infrastructure will continue to deliver the minimum for the lowest cost. The result will continue to be a user experience which, like reliability, is unacceptable.

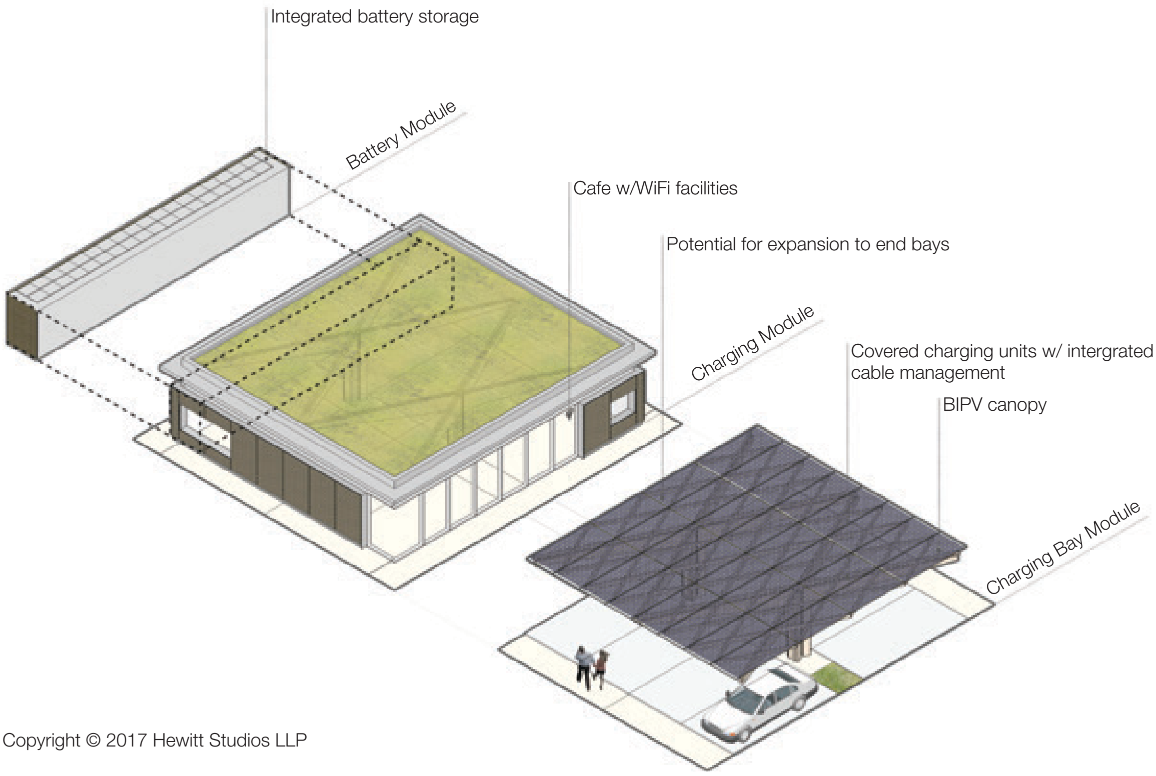
The preferred concept should be that of an EVCH, where, like a petrol filling stations, the services provided are tailored to customer demand, as this is ultimately what drives profit in a service environment.

An EVCH would offer a range of charging equipment to match the location. All units would be under cover and well lit: an attendant would be in place to assist with charger selection (in order to prevent PHEVs blocking rapid charge points), advise on services available, and provide security. The key feature of any EVCH would be to provide services to match the charge dwell time. This would be achieved on-site with a café, perhaps some franchised shops, an ATM and free Wi-Fi. Signal boosters would ensure good telephone communications on all networks for customers. For business customers, who would want to choose EVCHs as meeting places, there would be meeting rooms for hire (Hewitt Studios LLP, 2017). Figure 4.1 visualises a typical EVCH, while Figure 4.2 depicts the layout.

Figure 4.1: Visualisation of a typical EV charging hub

Source: Hewitt Studios LLP (2017)

Figure 4.2 Layout of a typical EV charging hub



Source: Hewitt Studios LLP (2017)

EVCHs would also support the other measures proposed in this paper. They would incorporate a storage battery to enable both grid management and smart charging. In addition to receiving energy from the EVCH's own solar panels, this could also provide energy storage for local wind and solar generators (Edwards, 2015).

This might seem as unlikely as the concept of a petrol filling station would have been in 1900, but if the UK is planning 100% ULEV new car sales by 2040 (Knight, Kivinen & Fell, 2015), then the construction of such EVCHs must start soon. It is therefore proposed that part of future government funding is directed towards encouraging the development and installation of some trial EVCHs.

4.3 Improving charge point reliability

To improve the current unacceptable failure rate, existing first-generation charge points must be replaced by more reliable machines.

There are precedents for establishing reliable manufactured items that meet a common standard already, notably in the motor industry, where it is called Whole Vehicle Type Approval (WVTA). According to the UK Vehicle Certification Agency (VCA, 2017):

> "Type approval is the confirmation that production samples of a design will meet specified performance standards. The specification of the product is recorded and only that specification is approved… Regulations require third-party approval – testing, certification and production conformity assessment by an independent body."

It will be seen that the main ingredients of this proven and successful process are appropriate regulations, independent testing to confirm compliance with those regulations, issue of certification, and inspection of the production process to confirm that each production unit conforms to the same standard as the product tested.

To be robust enough to meet the demands of increasing EV growth even over the next five years, public charge points need to move beyond a certification which is the simple electrical approval of internal electrical components. *Charge points need to be independently tested* to a 'whole unit' standard equivalent to the WVTA for vehicles. Compared with the extensively tested and type-approved vehicles which they charge, many charge points are primitive.

The current 13% failure rate is simply not acceptable on a network critical to increased sales of ULEVs. The AEVB may be able to assist in the short term by reducing failure downtime, but reducing the failure rate itself is a much bigger issue. Setting up a scheme similar to WVTA to ensure that charge point quality and reliability is equivalent to that of EVs will require new technical standards. Establishing such technical standards will take time, especially since it would make sense to have uniformity with the EU and possibly the USA.

5. Conclusions

5.1 General proposals and observations

- The charge point network (CPN) needs to be refined to match type and location of charge points to electric vehicle (EV) owners' preferred charging patterns. Although nearly all (93%) EV owners use the CPN, over 80% have access to home charging, and this is where most of their charging takes place. The majority (73%) of CPN use is at local fast and slow points in locations that the EV owners will in any case be visiting, such as shopping centres, hotels and leisure centres. The use of rapid charge points (27%), which are installed predominantly on motorways and trunk roads, is essential if battery electric vehicles (BEVs) are to have the credibility to replace internal combustion engine vehicles on longer journeys. It is also clear that future investment in the CPN must not just take the form of provision of rapid chargers at motorway service area (MSAs) and large fuel retailers (LFRs), but also address the need for an improved network of fast charge points in locations where EV drivers have a natural dwell time.

- The different EV charging mechanisms need to be better understood by decision-makers to ensure that relevant charge points are installed during the improvement of the CPN proposed in the AEVB. For example, not one of the 67,344 plug-in hybrid electric vehicle (PHEVs) registered in the UK at the end of June 2017 can charge at a rate greater than 3.6 kW (whatever the capacity of the AC charge point to which they are connected). Since PHEVs account for about two thirds of all EVs, there must be an adequate national provision of fast and slow charge points, including MSAs and LFRs, to meet their needs and to prevent them blocking rapid charge points.
- BEVs and PHEVs can share local charging but have completely different requirements on long journeys. Rapid charge points, which are essential to the use of BEVs on long journeys, *are irrelevant* to PHEVs, which cannot take advantage of their capabilities. This can result in PHEVs blocking BEVs from using rapid charge points.
- A network of rapid charge points at MSAs and LFRs on trunk roads is important to make increasing sales of BEVs viable. To maximise the value of government investment only 'double DC' (one CHAdeMO and one Combined Charging System (CCS)) DC rapid charge points should be installed in future.
- No further AC rapid (43 kW) charge points should be installed, as demand is almost static. The remaining 43 kW-enabled Renault ZOEs, which are the only vehicles capable of charging at 43 kW, are expected to number no more than 5,000 by the end of 2018,[2] and are provided for by the existing network of 722 connectors at 626 locations.
- The CPN needs to be able to cope with the significant increase expected to take place in BEV average battery capacity over the next few years. This will require higher-capacity (100 kW+) rapid charge points at MSAs and LFRs on trunk roads in order to maintain acceptable charge times.
- Charge point unreliability is a significant problem. A 13% national failure rate in June 2017 would not be acceptable for petrol filling stations, and will not be acceptable in the light of the drive to increase sales of ultra-low-emission vehicles. Whilst a full solution to this will require separate legislation, the AEVB draft legislation would allow repair times to be legislated for (as the Dutch already do) to increase charge point availability.
- Home charging at 7 kW is likely to remain the main method of charging EVs in the UK, despite increases in BEV battery capacity. However, it is essential that the requirement for smart charge points applies to home charge points as well as the public network, as this is where most of the energy transfer is likely to take place.
- Smart charging, grid balancing and avoiding the high cost of installing new grid supplies for multiple charge point installations will all require energy storage. In the short term this may require new storage batteries, but within five years ex-EV batteries are expected to become available in quantity, providing cost-effective energy storage solutions.

2 Author's own work based on RAC Foundation (2017)

- The existing system to support the creation and expansion of the CPN encourages quantity rather than quality. The current network is unattractive to use, and is unsuitable for encouraging the next wave of EV customers – people who have made a vehicle choice rather than a lifestyle statement. The Government must be prepared to support EV charging hubs, which are refuelling stations specifically designed for EVs.
- The Netherlands appear to be European leaders in most of the issues discussed here. Their NKL organisation has been instrumental in achieving this and they may have the potential to help the UK achieve similar results quickly. In addition, NKL's *Uniform Standards for Charge Points* may be a good starting point for a set of UK-relevant regulations. These standards already include protocols for exchanging information and preparing for smart meters of the sort that the AEVB requires.
- Whilst BEVs have been characterised by range anxiety in the media, the reality is that affordable BEVs with real-life ranges of around 200 miles are available now, and within three years most BEVs will offer ranges of 250 to 300 miles. Considering this in conjunction with improved rapid charging at MSAs and LFRs, it is clear that range anxiety is becoming a thing of the past.
- The draft legislation in the AEVB will address medium- and long-term CPN problems. The proposals in this paper would allow it to address also some important short-term problems as well as being more cost-effective by matching supply to demand.

5.2 Proposals for the Automated and Electric Vehicle Bill

- The AEVB already contains draft legislation for MSAs and LFRs and the wording appears general enough to include the requirement that only 'double DC' (CHAdeMO/CCS) rapid charge points are to be installed. In addition, every rapid charge point must be supported by three 7 kW AC outlets to provide AC charge for PHEVs. This is a highly cost-effective solution as it matches supply to demand.
- The AEVB also already contains draft legislation for MSAs and LFRs, and the wording appears general enough to permit the requirement that adequate energy storage becomes part of any installation at these sites. Any OLEV (Office for Low Emission Vehicles) grants applicable to these installations should be designed to encourage the use of energy storage.
- The AEVB requirements for smart charging (and therefore discharging) must be extended to home charging, where the majority of energy transfer is likely to take place. The requirement for rapid charge points to have smart charging capability should be removed, unless the rapid charge point is associated with adequate energy storage.
- The AEVB draft legislation wording should be extended to include some simple but essential improvements to the quality of the CPN. For example, a requirement for all rapid charge points to have weather protection and lighting.

- To partly address the unacceptable failure rate of current CPN charge points, the AEVB draft legislation allows repair times to be legislated for (as the Dutch already do). This would increase charge point availability in the short term.
- Discussions should take place with the Dutch NKL organisation to establish whether NKL's *Uniform Standards for Charge Points* would be a good starting point for a set of UK-relevant regulations. These standards already include protocols for exchanging information and preparing for smart meters of the sort that the AEVB requires.

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RAC Foundation
89–91 Pall Mall
London
SW1Y 5HS

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www.racfoundation.org

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