A feasibility study into a rapid chargepoint network for plug-in taxis

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About the Energy Saving Trust

Formed in 1992, Energy Saving Trust is a social enterprise with a charitable Foundation.

Through our partnerships we offer impartial advice to communities and households on how to reduce carbon emissions, use water more sustainably and save money on energy bills.

We work with governments, local authorities, third sector organisations and businesses.

Our activities include:

- delivering or managing government programmes
- testing low-carbon technology
- certification and assurance for businesses and consumer goods
- developing models and tools

Overarching all that the Energy Saving Trust does is a fundamental remit to reduce harmful carbon emissions. Our agenda is set by government obligations to reduce greenhouse gas emissions by at least 80% below base year levels by 2050. Transport is a major contributor to the UK's energy demand and greenhouse gas emissions and car and van fleets make up approximately half of all new car registrations. The Energy Saving Trust works to influence end users and the supply chain to provide advice on best practice to help reduce fuel use and consequently CO_2 emissions.

The past five years has seen the Energy Saving Trust move to a leadership position in delivering advice and support to organisations wishing to further investigate the business case for including ultra-low emission vehicles (ULEVs) on fleet.

Acknowledgements

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Executive Summary

Background

Energy Saving Trust was commissioned by Transport for London (TfL) in 2013 to review the feasibility of a rapid chargepoint network for plug-in taxis in London, determine suitable locations for infrastructure and provide advice on operational viability. This report is part of a suite of studies being undertaken by TfL to understand where rapid charge infrastructure might be needed to serve a variety of potential users in London.

From January 2018, all newly licensed London taxis will be zero emissions capable (≤50g/km CO_2 with a minimum zero emission range of 30 miles). This will complement the introduction of the world's first big city Ultra Low Emission Zone (ULEZ) in central London currently planned in 2020 but under review following a series of consultations through 2016 and 2017.

- **Phase 1 – July 2016:** Air quality consultation on high level proposals including the principle of introducing a new Emissions Surcharge to discourage the oldest vehicles from driving in Central London and changes to the plans for the Ultra Low Emission Zone (ULEZ), high pollution alerts and incentivising the use of cleaner vehicles.
- **Phase 2 – Autumn 2016**: Policy consultation on transport related proposals including a detailed statutory public consultation on the introduction of a new Emissions Surcharge
- **Phase 3 – 2017**: A detailed statutory public consultation on the transport related proposals including the widening of the ULEZ boundary to include more of inner London and proposal to tighten the emission standards for the London-wide Low Emission Zone

Plug-in vehicles and rapid charging

Plug-in vehicles emit zero tailpipe emissions while driving using electric power and can therefore make a significant contribution towards air quality objectives. According to TfL's research, taxis are responsible for 19% of PM_{10} emissions and 18% of NO_x emissions arising from road transport sources in central London[1].

Taxis' duty cycles make them ideal for utilising plug-in technology, as they are driven predominantly in an urban, stop-start environment, where battery electric vehicles operate most effectively.

'Rapid charging' involves charging a plug-in vehicle at a rate of 43kW or more, which would typically provide a vehicle with the capability of charging at this rate with an 80% charge in less than half an hour. Access to rapid charging offers three potential benefits for taxis:

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[1] Source: TfL modelling based on the LAEI 2010

1. The limited range on a single charge is effectively no longer an issue given the speed at which vehicles can be recharged, eliminating excess driver downtime.
2. The low cost per mile when driving on electric power reduces total cost of ownership
3. Vehicles will produce zero tailpipe emissions and therefore reduce the negative impact on London's air quality.

Rapid chargepoint network

This report proposes a rapid chargepoint network for taxis based on current vehicle movements. In designing this network, the intention is to minimise disruption to drivers' working patterns.

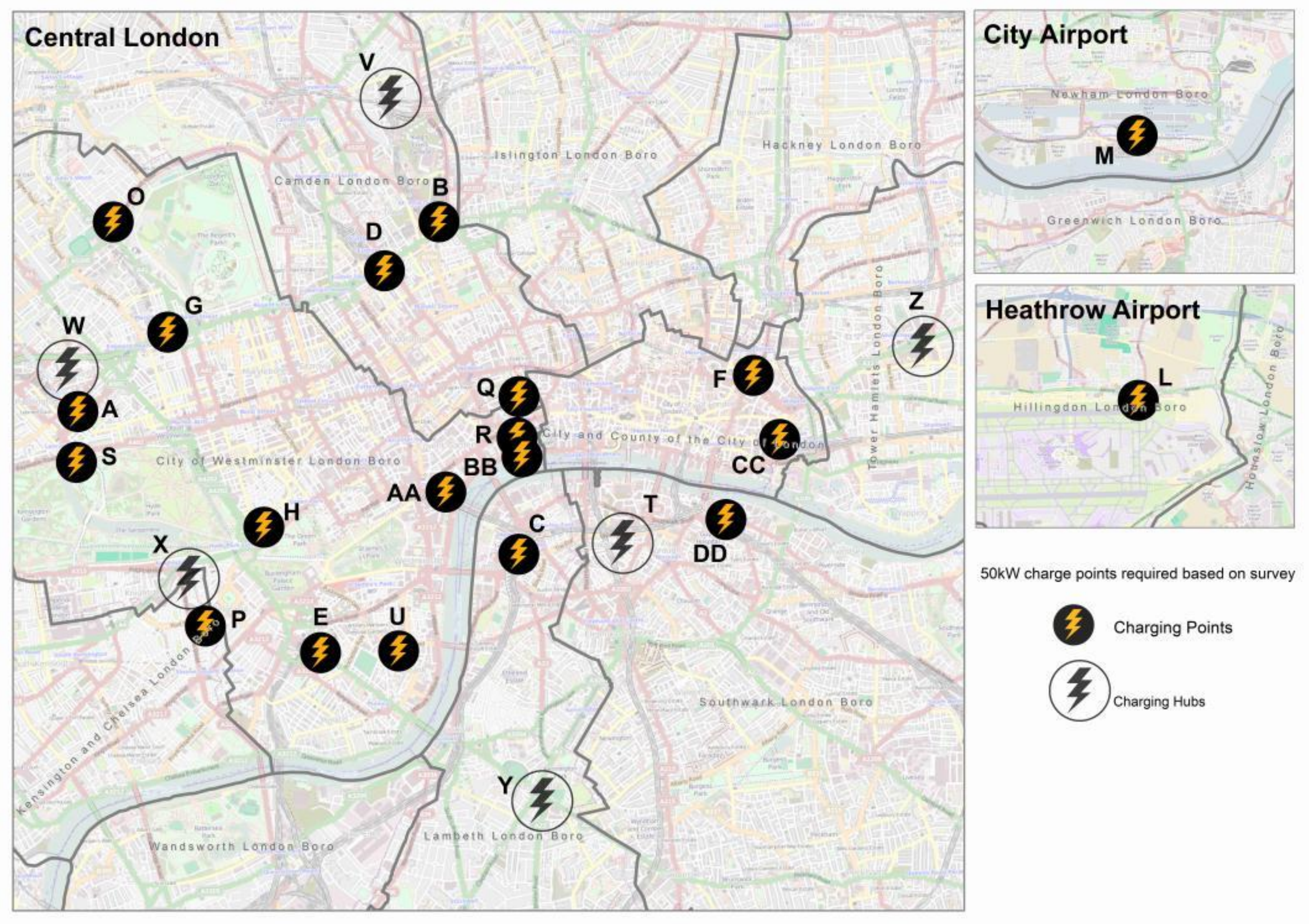
- Chargepoints should be sited at or close to where taxis are stationary in large numbers, such as key ranks and drivers' break locations. Strategically locating chargepoints is also necessary to maximise chargepoint utilisation rates.
- The rate of charging should allow drivers to recharge their vehicles without being off the road for longer than they are currently.

We estimate that by the end of 2018 approximately 90 rapid chargepoints will be required to support the introduction of 1,400 taxis, based on the current replacement cycle of the vehicles. Additional financial support being made available to drivers by TfL, in particular a voluntary decommissioning scheme, and the increase in replacements typically seen when a new vehicle is launched is anticipated to lead to the following scenarios:

Scenario	Number of chargepoints (2018)
1 Baseline, 50% E-REV[2]	88
2 Baseline, 100% E-REV	73
3 Accelerated uptake, 50% E-REV	150
4 Accelerated uptake, 100% E-REV	126

Based on taxi drivers' current working patterns, the following illustrative locations are suggested:

[2] Also applies 100% E-REV and 50% of drivers both commute and work in electric drive mode



Illustrative rapid chargepoint locations

- Stations:
  - Paddington (A), King's Cross / St. Pancras (B), Waterloo (C), Euston (D), Victoria (E), Liverpool Street (F), Marylebone(G), Charing Cross (AA), Fenchurch Street (CC) and London Bridge (DD).
- Hotels:
  - In W1 postcode area.
- Airports:
  - Heathrow (L), London City (M).
- Cabmen's shelters:
  - Wellington Place NW8 (O), Pont Street SW1 (P), Temple Place WC2 (BB).
- Rest ranks:
  - Lincoln Inn Fields WC2 (Q), Strand WC2 (R), Lancaster Gate W2 (S).
- Additional locations:
  - Great Suffolk Street SE1 (T), Horseferry Road SW1 (U), Camley Street King's Cross (V), North Wharf Road near Paddington (W), Hyde Park Corner (X), Oval / Kennington (Y), Whitechapel (Z).

In order to provide the forecast number of chargepoints (c.90) in and around central London between one and three rapid chargepoints should be installed at each location. The exact number to be installed at a given site will depend on the results of Distribution Network Operator surveys to establish local grid capacity.

Timescale for network introduction

Pre-2018

- Install approximately 45 rapid chargepoints by 1 January 2018, using locations provided in this report as a guide.
- Provide assistance for early adopters to install a dedicated home charging solution.
- Identify sites where grid capacity exists for additional chargepoints and/or carry out upgrades as required.

2018

- Monitor utilisation rates for each chargepoint, and use this information to add chargepoints to existing sites as required.
- Increase number of chargepoints to approximately 90 by the end of 2018 (refining the number required appropriately based on utilisation rates and vehicle uptake rates).

2019 onwards

- Expand number and geographical coverage of rapid chargepoints across Greater London based on continued monitoring of utilisation rates.
- Continue to plan ahead to ensure that grid capacity can meet demand.

Comments on the feasibility of a rapid chargepoint network for taxis

The purpose of this study is primarily to determine the feasibility of a rapid chargepoint network for taxis. Therefore this report does not consider the viability of other options such as slow, fast or inductive charging in detail. It is presumed however that fast charging at 20/22 kW may be required in some central areas, such as Westminster, where space to install rapid chargepoints is at a premium. Our research suggests that it is feasible – and necessary – to implement a network of rapid chargepoints, supported in central areas by fast chargepoints to support the introduction of zero emission capable taxis and ensure that the potential financial and environmental benefits are maximised. However, in order to ensure the network is successful, it is critical that the following four areas are addressed.

1. **Zero emission capable vehicles licensed to operate as taxis should be available by 2018. All taxis should be rapid charge capable in order to make a rapid charge network feasible.**

- Several manufacturers are developing zero emission capable vehicles designed to meet the Conditions of Fitness for use as a London taxi. All vehicles described in this report can be driven without producing any tailpipe emissions, although the choice of technology includes both pure electric vehicles and extended range electric vehicles. Final decisions have not been reached or published by all manufacturers about incorporating rapid charge capability into the potential taxis. We recommend TfL determine the charging capability for all London taxis and incorporate a minimum charging specification into the conditions of fitness.
- When these vehicles are presented for licensing, TfL should work with the manufacturers to establish electrically driven range in ‘real-world’ conditions and petrol consumption (of plug-in hybrid or extended range electric vehicles) once the battery has been depleted.

2. **Sufficient rapid chargepoints should be installed at strategic locations across London, supported by appropriate KPIs and data management**

- Taxi drivers in London typically stop for 15 minutes or fewer when they take breaks. Therefore rapid (rather than slow or fast) chargepoints are desirable so that drivers can recharge vehicles without additional downtime. 50kW chargepoints (compatible with both major DC protocols) should be installed; they will supply approximately up to 40 miles of additional range in 15 minutes.
- Chargepoints should be reliable and supported by an appropriate back office system. We recommend that TfL sets KPIs for licensed network operator(s) to ensure they provide sufficient, reliable and well maintained chargepoints. TfL should also collate and monitor chargepoint utilisation data to plan the expansion of the network beyond 2018.

3. **Taxi drivers in extended range and plug-in hybrid vehicles should use rapid charging rather than rely on the petrol engine once the battery is depleted**

- Even if rapid charge compatible vehicles and rapid chargepoints are provided, there is a significant risk that drivers of extended range and plug-in hybrid vehicles will rely on the petrol engine once the battery is depleted. This will reduce the environmental and financial effectiveness of the new vehicles and will lead to significant under-utilisation of chargepoints. Drivers should, whenever practicable, use rapid chargepoints once the vehicle battery is depleted.
- Part of the solution will be to ensure that the cost of rapid charging is less than the cost of petrol, on a pence per mile basis. However, a price incentive to use rapid charging will not be sufficient by itself. TfL should consider the risks associated with drivers not

utilising their vehicles effectively and ensure the use of rapid charging becomes normal practice.

4. **Electricity supply constraints at the substation level are potentially the biggest barrier to rapid chargepoint provision. Plans for mitigating this should be drawn up.**

- Installing rapid chargepoints will add significant demand to the already constrained electricity supply system in London. Given the estimated number of rapid chargepoints required to support zero emission capable taxis, the cost of upgrading the electricity network is likely to be the greatest potential barrier to developing rapid charge infrastructure.
- Some installations may require a new substation which could cost up to £200,000, in addition to the cost of land to site chargepoints and a substation. Distribution Network Operators are not responsible for paying for upgrades, except in instances where they have demonstrated that it will benefit network users. If prospective chargepoint operators are expected to be responsible for the full upfront cost of any network reinforcement, it is unlikely that they will be able to produce a business case for installing chargepoints.
- TfL and the appropriate Distribution Network Operators should collaborate from the outset to manage rapid chargepoint installations and any necessary supply upgrades, including integrating chargepoints into new built environment developments where practicable.
- Subsequent to the initial (unpublished) draft of this report TfL has confirmed that it will identify and enable sites for the installation of charging infrastructure across the TfL, borough and private sector estates. Enabling works will include upgrades of power capacity and groundworks to make the site suitable for charge point installations.

01 Introduction

Background

Energy Saving Trust was commissioned by Transport for London (TfL) in 2013 to review the feasibility of a rapid chargepoint network for plug-in taxis in London. We were required to determine suitable locations for such infrastructure and provide expertise and advice on the operational viability of charging infrastructure applicable to the business models operated within these industries.

The study looks specifically at the practical issues that would be faced by the various parties concerned with zero emission capable (≤50g/km CO_2 with a minimum zero emission range of 30 miles) taxis and rapid charge infrastructure. The methodology included discussions and data collected from taxi drivers and their representatives, taxi manufacturers and UK Power Networks (the Distribution Network Operator covering most of Greater London). The data collection included an online survey of taxi drivers which explored their working patterns to help map out a potential network of rapid chargepoints, as well as exploring their perceptions of the potential barriers they see to operating plug-in taxis, with specific reference to charging issues.

This feasibility study will inform operators, drivers and fleet proprietors looking to invest in plug-in taxis and who have identified the need for additional charging infrastructure. Additionally it will assist policy makers and the private sector in supporting the deployment of rapid charge infrastructure across London.

This study looks only at what rapid charging infrastructure would be needed to serve taxis in central London. It forms part of a wider suite of research being undertaken by TfL to understand the needs of all users, including private hire, commercial fleets and car clubs. This research, alongside the results of TfL's market and stakeholder engagement work, will be used to inform the deployment strategy for rapid chargepoints in London.

London taxis

TfL is responsible for licensing London's taxis. There are approximately 22,900 licensed taxis in London and nearly 25,000 taxi drivers. London's iconic cabs are the only vehicles that can be hailed in the street or from one of around 500 ranks situated at prominent places including rail, Underground and bus stations. TfL appoints ranks on the public highway in all boroughs except the City of London where taxi ranks are appointed by the Commissioner of the City of London Police. This report only considers licensed taxis and does not include the private hire market which will be looked at separately by TfL.

A licensee survey carried out by TfL in 2015 found that almost half of drivers report using a booking app and more than a quarter a radio circuit.

TfL is responsible for the annual inspection of all vehicles and ensuring that all taxi drivers are of good character, medically fit and have passed the world-famous 'Knowledge' – the examination for becoming a licensed taxi driver in the Capital.

The majority of the taxi fleet consists of TX4, TX2, TX1 and Mercedes Vito models plus a small number of Metrocab models. All taxis must meet the specifications detailed in the "Construction and Licencing of Motor Taxis for use in London – Conditions of Fitness" document. Additionally, from January 2012, a maximum age limit of 15 years has been introduced for taxis (with limited exemptions). Following a consultation held in July and August 2015[3], it was decided to maintain this 15 year limit but introduce a voluntary decommissioning scheme for taxis over 10 years old. The majority of drivers (approximately two thirds of those we surveyed) own their taxi, while the remaining one third rent or lease the vehicle.

There are two types of black cab driver in London:

- All London (Green Badge) – these drivers can pick up passengers anywhere in London.
- Suburban (Yellow Badge) – these drivers can only pick up passengers in certain outer London boroughs.

Each day in London there are about 185,000 black cab journeys. An average black cab journey is about three miles and the average black cab fare is about £13. These transport about 278,000 passengers. The average distance travelled per journey is 2.9 miles; which means that about 810,000 passenger miles are covered in London by taxi on an average day[4].

Air quality in London

Air pollution refers to the substances in the air that harm human health, welfare, plant or animal life. Most pollution in London is caused by road transport and domestic and commercial heating systems. There are two key pollutants of concern associated with road transport:

- PM (10 and 2.5): Suspended particulate matter categorised by the size of the particle (for example PM10 is particles with a diameter of less than 10 microns).
- Nitrogen dioxide (NO_2): All combustion processes produce oxides of nitrogen (NOx). NOx is primarily made up of two pollutants - nitric oxide (NO) and nitrogen dioxide (NO_2). NO_2 is of most concern due to its impact on health. However NO easily converts to NO_2 in the air - so to reduce concentrations of NO_2 it is essential to control emissions of NOx.

Poor air quality has a significant impact on the health of London residents. PM_{10} is associated with health impacts including cardiovascular mortality[5]. Children, the elderly and people with existing respiratory illness suffer disproportionately from the effects of air pollution. The Mayor

[3] https://consultations.tfl.gov.uk/environment/ulez-2

[4] Taxi/PHV Diary Survey 2009 Provided by GfK Consumer Services, January 2010

[5] http://www.theicct.org/sites/default/files/publications/ICCT_HealthClimateRoadmap_2013_revised.pdf

published a study in 2010[6] estimating that long term exposure to fine particles had an impact on mortality equivalent to over 4,000 deaths in London in 2008. A subsequent report published in 2015 by Kings College London on behalf of TfL and the GLA[7], suggests that the impact on mortality could be equivalent to as many as 9,500 deaths per annum. In 2014, a report by Public Health England found that "estimates of the fraction of mortality attributable to long-term exposure to current levels of anthropogenic particulate air pollution" exceeds 8% in some of the most polluted London boroughs[8].

The health impacts of NO_2 are less well defined, but research reported by the World Health Organisation indicates that long term exposure exacerbates the effects of asthma and can lead to inhibited development in lung capacity and function particularly in children. City-dwellers are particularly exposed, as ground-based transport accounts for just under half of total NOx emissions in London from which nitrogen dioxide originates. European legislation sets limits on human exposure to air pollution. The NO_2 limits should have been achieved by 1 January 2010 and the European Commission has launched legal proceedings against the UK for its failure to cut excessive levels of nitrogen dioxide.

Impact of taxis on air quality

There are approximately 22,900 taxis licensed to operate in London. While this is a relatively small fleet as a proportion of all vehicles in the capital, they have a disproportionate impact on air quality, due to the relatively high mileage they cover, and their concentrations in certain areas of the city. Additionally taxis are almost all powered by diesel engines and therefore are a significant source of NO_x and PM_{10} emissions.

Modelling work was undertaken by TfL to inform the feasibility study for the Ultra Low Emission Zone (ULEZ) in 2020 and estimates made of future emissions in central London (2020). Road transport is responsible for 32% of total PM_{10} emissions in central London[9]. The sources of emissions of PM_{10} from road transport are shown in the chart below.

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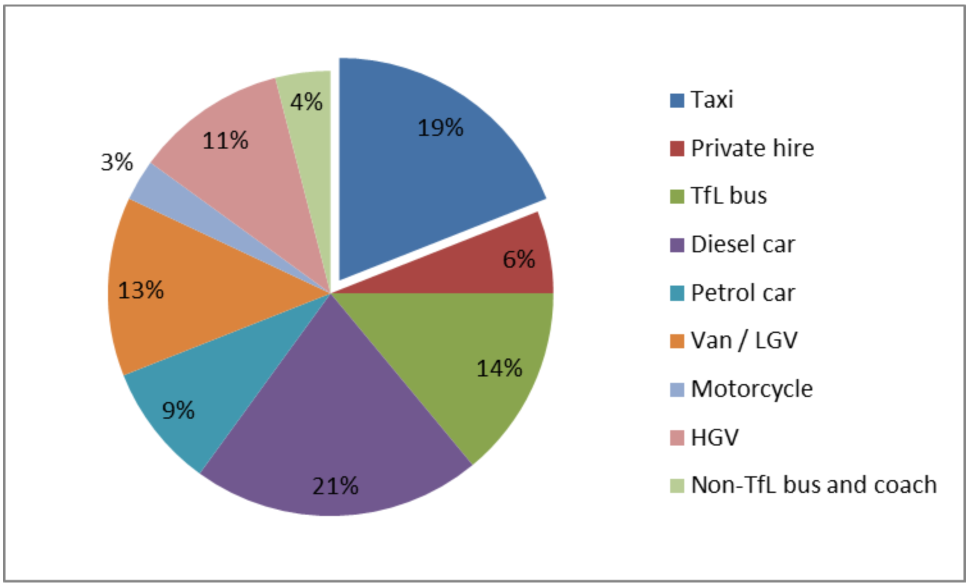
[6] http://www.london.gov.uk/sites/default/files/Health_Study_%20Report.pdf

[7] https://www.kcl.ac.uk/lsm/research/divisions/aes/research/ERG/research-projects/HIAinLondonKingsReport14072015final.pdf

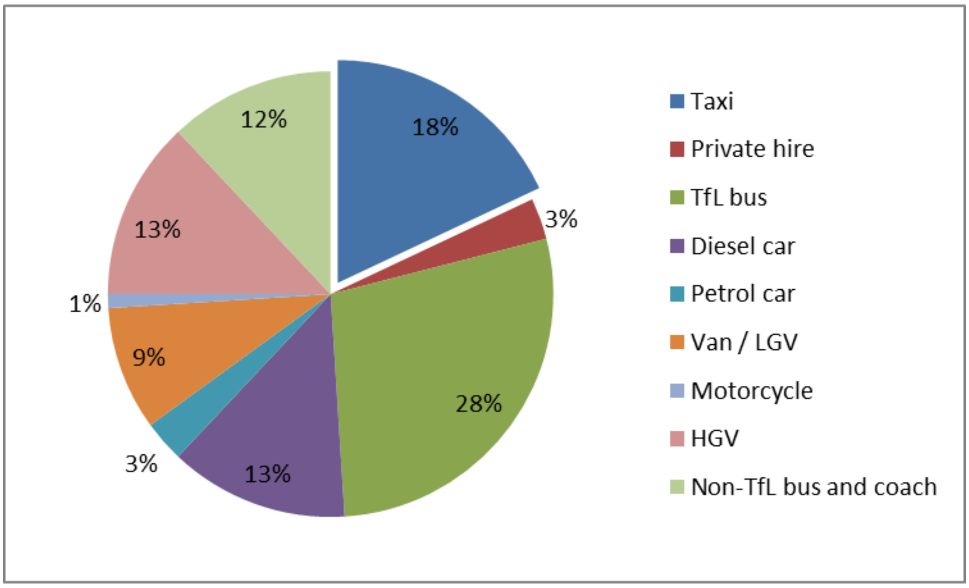
[8] Public Health England (2014) Estimating Local Mortality Burdens associated with Particulate Air Pollution. http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317141074607

[9] Source: TfL modelling based on the LAEI 2010



Breakdown of PM_{10} emissions from road transport in London

Road transport is responsible for 27% of total NO_x emissions in central London[10]. The sources of emissions of NO_x from road transport are shown in the chart below.



Breakdown of NO_x emissions from road transport in London

According to TfL's research, taxis are responsible for 19% of PM_{10} emissions and 18% of NO_x emissions arising from road transport sources in central London[11].

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[10] Source: TfL modelling based on the LAEI 2010

[11] Source: TfL modelling based on the LAEI 2010

Air quality policy

Ambitious plans are in place to improve London's air quality by targeting the most significant sources of pollution, including taxis. In May 2009, the previous Mayor published the *Electric Vehicle Delivery Plan*[12], which committed to a range of initiatives to achieve a target of 100,000 electric vehicles on London's roads "as soon as possible". Subsequently the previous Mayor outlined a range of measures to tackle air pollution via the *Mayor's Air Quality Strategy* (MAQS), published in 2010.

In September 2014 the *Transport Emissions Roadmap*[13] (TERM) was published, focusing on how to reduce emissions from ground–based transport in London. The TERM includes a range of possible new measures that the Mayor, TfL, the London boroughs, the Government, EU and other parties should consider to help meet the challenge of air pollutants and CO_2 emissions in London. The measures are grouped into a top ten list:

1. Implementing an Ultra Low Emission Zone (ULEZ) in London
2. Tightening the Low Emission Zone
3. Making traffic management and regulation smarter
4. Helping Londoners tackle air pollution and climate change
5. Driving the uptake of low emission vehicles
6. Cleaning up electricity for London's transport
7. Transforming London's bus fleet
8. Delivering a zero emission taxi fleet
9. Transforming London's public and commercial fleets
10. Developing Low Emission Neighbourhoods.

The measures described in the document are linked to the stakeholders who can help deliver them and is intended as a guide to on-going discussion, rather than a finalised plan.

In October 2014 TfL launched a consultation into proposals to introduce an Ultra Low Emission Zone (ULEZ) in central London by 2020. This aims to deliver significant benefits in air quality, reduce CO_2 emissions, promote sustainable travel modes and stimulate the mass take-up of low emission vehicles. The consultation ran from 27 October 2014 and closed on 9 January 2015. On 26 March 2015 the previous Mayor confirmed the introduction of the ULEZ in central London and a launch date of 7 September 2020.

The details of the ULEZ are as follows:

- Cars and small vans must be Euro 6 compliant for diesel engines (registered from 1 September 2015 so five years old or fewer in 2020) and Euro 4 compliant for petrol

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[12] http://www.london.gov.uk/sites/default/files/electric-vehicles-plan.pdf

[13] https://www.tfl.gov.uk/cdn/static/cms/documents/transport-emissions-roadmap.pdf

engines (registered from 1 January 2006 so 14 years old or fewer in 2020). Non-compliant vehicles can still drive in the zone but they will be required to pay a daily charge of £12.50.

- Large vans and minibuses must be Euro 6 compliant for diesel engines (registered from 1 September 2016 so four years old or fewer in 2020) and Euro 4 compliant for petrol engines (registered from 1 January 2007 so 13 years old or fewer in 2020). Non-compliant vehicles will be required to pay a daily charge of £12.50.
- Heavy goods vehicles, buses and coaches must be Euro 6 compliant (registered from 1 January 2014 so six years old or fewer in 2020) except TfL buses which are required to meet a higher standard. Non- compliant vehicles will be required to pay a daily charge of £100.
- Motorcycles and similar vehicles must be Euro 3 compliant (registered from 1 July 2007 so 13 years old or fewer in 2020). Non-compliant vehicles will be required to pay a daily charge of £12.50.

In 2016 the new mayor, Sadiq Khan, instigated a review of the size and date of introduction of the ULEZ in order to more urgently address the poor air quality in the city with a series of consultations[14] through 2016 and 2017.

- **Phase 1 – July 2016:** Air quality consultation on high level proposals including the principle of introducing a new Emissions Surcharge to discourage the oldest vehicles from driving in Central London and changes to the plans for the Ultra Low Emission Zone (ULEZ), high pollution alerts and incentivising the use of cleaner vehicles.
- **Phase 2 – Autumn 2016**: Policy consultation on transport related proposals including a detailed statutory public consultation on the introduction of a new Emissions Surcharge
- **Phase 3 – Autumn 2017**: A detailed statutory public consultation on the transport related proposals including the widening of the ULEZ boundary to include more of inner London and proposal to tighten the emission standards for the London-wide Low Emission Zone

The previous ULEZ consultation held during July and August 2015 confirmed the new licensing requirements for taxis in London. These include the requirement for all taxis licensed for the first time to have a ZEC specification from 1 January 2018, the introduction of a voluntary decommissioning scheme for taxis over 10 years old and the introduction of grants for the purchase of ZEC taxis[15]. These requirements are not being consulted on and will remain as confirmed.

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[14] https://consultations.tfl.gov.uk/environment/air-quality-consultation-phase-2/?cid=airquality-consultation#Consultation%20Stages

[15] https://consultations.tfl.gov.uk/environment/ultra-low-emission-zone

https://consultations.tfl.gov.uk/environment/ulez-2

London has been allocated £10 million in the National Infrastructure Plan for charging infrastructure. In addition, London has a £65 million fund to help support London taxi drivers' transition to zero emission capable vehicles. In order to encourage the removal of the oldest taxis from the fleet, TfL will introduce a voluntary decommissioning scheme from mid-2017 until 2020. Owners of taxis over 10 years old will be able to claim a payment of up to £5,000, depending on the age of the vehicle, from TfL by forfeiting the ability for that vehicle to be relicensed as a taxi in London. Taxi drivers will also benefit from an additional £3,000 grant, on top of the government's plug-in car grant, towards the purchase of a new taxi.

Climate change

At a national level, plug-in and other low emission vehicles contribute towards the UK's climate change policy objectives. The 2008 Climate Change Act commits the UK to reducing greenhouse gas emissions by at least 80% (from the 1990 baseline) by 2050. In order to achieve this target, nearly every new vehicle sold in the UK will need to have zero tailpipe emissions by 2040. Other technologies such as hydrogen fuel cell vehicles are likely to have a growing share of the market by that date, but it is anticipated that plug-in or inductively charged vehicles will comprise the majority of new low emission vehicle sales in the short to medium term.

Plug-in vehicles for use as taxis

There are three main types of plug-in vehicle.

Vehicle type	Definition
Battery electric vehicle (BEV or pure-EV)	A vehicle powered only by electricity. The vehicle is charged by an external power source and incorporates regenerative braking which helps to extend the available range.
Plug-in hybrid electric vehicle (PHEV)	A vehicle which combines a battery, electric drive motor and an internal combustion engine (ICE) and the ability to charge the battery from an external power source. The vehicle can be driven by the ICE, by the electric drive motor, or both together.
Extended range electric vehicle (E-REV)	A vehicle which combines a battery, electric drive motor and an ICE. The electric motor always drives the wheels with the ICE acting as a generator to provide electricity when the battery is depleted.

Types of plug-in vehicle

Please refer to the technical overview in section two for more information on these different vehicle types.

All types of plug-in vehicle emit zero tailpipe emissions while driving using electric power. Each vehicle type has different advantages and disadvantages for use as taxis:

Vehicle type	Advantages	Disadvantages
Battery electric vehicle (BEV or pure-EV)	Typically the cheapest of the three to purchase or lease. Zero tailpipe emissions at all times, therefore no negative impact on local air quality.	Short range on a single charge, typically 80 to 100 miles.
Plug-in hybrid electric vehicle (PHEV)	Typically slightly more expensive than a pure-EV but cheaper than an E-REV. Longer total range than a pure-EV, combining ICE and electric power.	Short electric-only range, so cost savings and air quality benefits may be reduced
Extended range electric vehicle (E-REV)	Longer total range than a pure-EV, combining ICE and electric power. Longer electric-only range than a PHEV, increasing benefits in terms of running cost and air quality.	Typically the most expensive of the three types of plug-in vehicle

Advantages and disadvantages of plug-in drivetrains for taxis

Plug-in vehicles are increasingly becoming a normalised technology, as manufacturers bring a wider range of cars and vans to market. Range available from a single charge is increasing, and purchase prices are decreasing. The UK Government has supported their uptake by providing incentives including the Plug-in Car and Van Grants and zero Vehicle Excise Duty, whilst TfL provides a 100% discount from the London Congestion Charge. Data published by the Society of Motor Manufacturers and Traders (SMMT) shows that 27,718 Plug-in Car Grant eligible vehicles were registered in 2015 in the UK; a 105% increase on 2014.

Plug-in vehicles emit zero tailpipe emissions while driving using electric power, making them the ideal solution to reduce the impact of taxis on London's air quality. Equally, taxis' duty cycles make them ideal for utilising plug-in technology (when used in conjunction with rapid charging):

- They are driven predominantly in an urban, stop-start environment, where plug-in vehicles operate most effectively.
- Longer journeys (over 80 miles) are less common, so most trips can be carried out on a single charge.
- Plug-in hybrids or extended range EVs could meet the needs of drivers who carry out a mixture of predominantly urban driving with occasional longer journeys.
- Taxis' duty cycles already include periods of downtime, for example waiting for a passenger or during breaks.

Additionally, plug-in vehicles can reduce expenditure for taxi drivers and operators, costing as little as three pence per mile[16] in electricity depending on the price paid per kWh. The financial benefits for drivers are key to adoption of the vehicles and must not be overlooked.

[16] Assuming 9 pence per kWh and vehicle energy consumption of 210 Wh/km

Introduction to rapid charging for taxis

London already has publically accessible plug-in vehicle chargepoints available through the Source London network and membership scheme. This network is intended to provide private and business users, who would usually charge their vehicles overnight, with a top-up facility during the day. At the time of writing there are over 850 chargepoints in the Source London network. BluePoint London Ltd took over the scheme in the summer of 2014 and plan to expand the network to 6,000 chargepoints by 2018. However, the majority of the Source London chargepoints currently provide a slow rate of charge which would not meet the commercial needs of taxi drivers. In addition there are a number of other operators providing vehicle charging infrastructure across greater London.

'Rapid charging' involves charging a plug-in vehicle at typical rates of at least 43kW AC or 50kW DC, which would supply the majority of modern vehicles with an 80% charge in 30 minutes or fewer. This equates to increasing the vehicle's range by approximately three miles for every minute spent on charge. For a pure-EV with a 100 mile range, being able to access a rapid chargepoint effectively doubles its daily range with minimal impact on time spent off the road.

Access to rapid charging offers several potential benefits for taxis:

1. The limited range on a single charge is effectively no longer an issue given the speed at which vehicles can be recharged, eliminating excess driver downtime.
2. The low cost per mile when driving on electric power offsets the high upfront vehicle cost, offering a competitive total cost of ownership compared to conventionally fuelled alternatives.
3. Vehicles will produce zero tailpipe emissions and therefore reduce the negative impact on London's air quality.
4. It allows more drivers to use pure-EVs, or to drive PHEVs and E-REVs on electric power, which produce zero tailpipe emissions and thereby reduce the negative impact on London's air quality.

With the right infrastructure in the right locations, rapid charging can be built into drivers' working patterns with minimal disruption, allowing them to cover the mileages they need to do their job. As TfL specifies the requirements that vehicles must meet in order to be licensed for use as a taxi in London they can ensure that only practical, efficient vehicles are licensed for use as taxis.

Cities including Amsterdam and Barcelona are currently deploying electric taxi fleets supported by rapid chargepoints. Rapid charging infrastructure is being installed in London but relatively slowly, challenges facing owners and operators of the charge points include:

- The relatively high costs involved in purchasing and installing the equipment
- Constraints on the supply of sufficient power from the electricity network
- The difficulty involved in planning a cohesive network in London across 33 boroughs, each with their own planning requirements.

- Lack of available space.
- Lack of demand to support a dedicated rapid charge network for taxis as there are no compatible vehicles currently available.

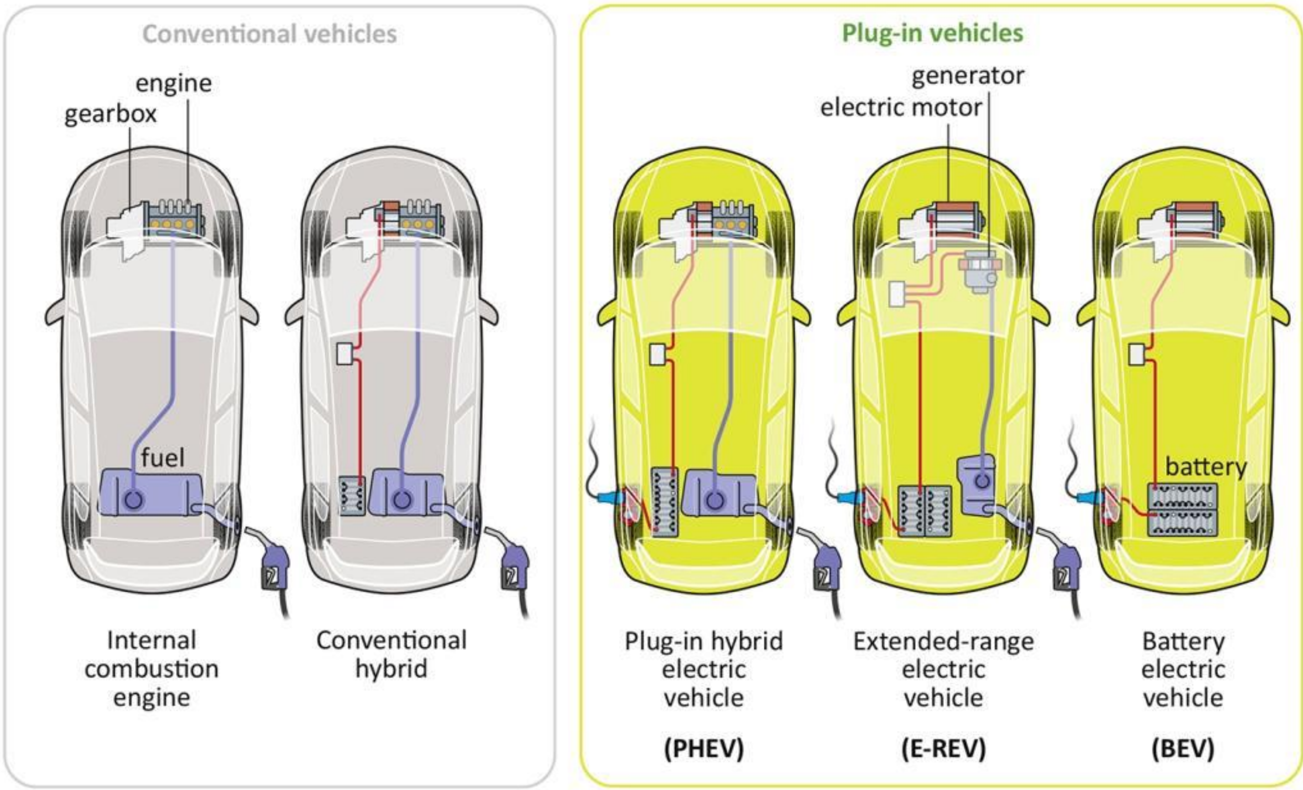
Despite these challenges, a rapid chargepoint network is both feasible and necessary to support the introduction of zero emission capable taxis. It is important that all stakeholders work together to ensure London is ready for the introduction of these vehicles and to keep pace with other cities in the UK and beyond.

02 Technical overview

Before discussing the feasibility of a rapid charge network for taxis, it is necessary to introduce the different vehicle technologies which may be utilised by vehicle manufacturers and the complementary charging technologies that could be used in the development of a charging network.

Vehicle technology

The diagram below[17] illustrates the technologies used by manufacturers to power their vehicles and helps explain the difference between them. Each technology reading from the left hand side of the diagram is covered in turn below.



Conventional petrol or diesel: These vehicles burn their fuel in an internal combustion engine (ICE) which drives the vehicle's wheels via a gearbox. This is the most common form of propulsion for vehicles on the road today. Vehicles running on road fuel gases (such as LPG) are included in this description.

Conventional hybrids: In certain driving conditions, particularly in urban areas, it is possible to improve a vehicle's efficiency by "hybridising" the drivetrain. This is usually achieved by the

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[17] Source - Office for Low Emission Vehicles

addition of a storage battery which is charged by regenerative braking (converting the kinetic energy of the car into electricity which is stored in the battery). This stored energy is then used to drive an electric motor which can assist the conventional engine to drive the wheels or drive them entirely for a short distance (usually less than a mile). Using energy generated by slowing the vehicle down to help drive it when accelerating, or driving at low speeds, aids efficiency and therefore reduces fuel consumption.

Plug-in hybrid electric vehicle (PHEV): These vehicles combine the battery, electric motor and ICE in the same way as a conventional hybrid; however the larger battery provides a longer electric only driving range. By charging the battery from an external power source (such as a vehicle chargepoint) the petrol or diesel consumed by the vehicle is reduced over a given distance. The vehicle can be driven a similar total distance (or range) as a conventional ICE, reverting to petrol or diesel power when the battery charge has been depleted. In urban conditions with the battery depleted the vehicle operates in the same way as a conventional hybrid and therefore continues to reduce fuel consumption in these conditions.

Extended-range electric vehicle (E-REV): An E-REV also combines a battery, electric motor and an ICE; however the electric motor always drives the wheels, with the ICE acting as a generator when the battery is depleted, to both maintain the battery at a minimum level of charge and provide electricity for the electric motor(s) driving the wheels. In some vehicles the ICE may recharge the battery which powers the electric motors driving the wheels. The vehicle can also be recharged from an external power source (such as a vehicle chargepoint). The battery in an E-REV is usually larger than in a PHEV, providing a longer electrically driven range.

Battery electric vehicle (BEV or Pure-EV): Powered only by electricity, a pure-EV usually has a larger battery than an E-REV or a PHEV. The vehicle is charged by an external power source and incorporates regenerative braking which helps to extend the available range.

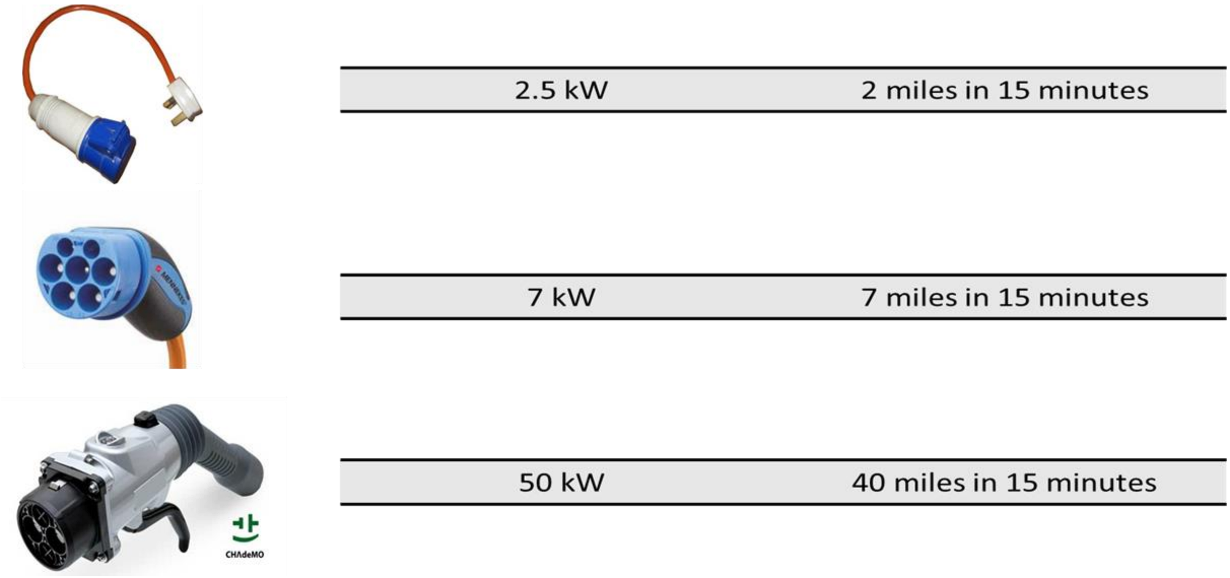
Battery size and range

The storage capacity (size) of a battery is the main factor that determines the range of a vehicle and is measured in kWh. The larger the battery, the longer it takes to charge at any given charging rate. Manufacturers may specify their vehicles with a single or several different charging technologies. The higher the charging rate, the shorter the time will be to recharge the battery.

Charging plug-in vehicles

The taxi driver survey (section three) suggests that a charging period of 15 minutes would, for many drivers, cause little or no disruption to their working day. The rate at which a vehicle is charged can be expressed more usefully as the mileage added for a particular time on charge.

The following diagram shows how useful rapid charging is when the time available for charging is constrained[18].



Standard and fast charging

Vehicle charging uses either alternating current (AC) or direct current (DC). AC supply is almost always used for slower rates of charging (typically 3.5 kW or 7kW). A charging cable, usually carried in the vehicle, is used to connect an on-board battery charger to the 230 volt AC supply. Where a cable is fitted with a standard, domestic 3 pin plug (BS 1363), the current is usually restricted to 10 amps to help protect the electrical circuit to which it is connected.

For home charging it is recommended that a dedicated chargepoint is installed which is usually rated at 16 amps (providing c. 3.5kW) or optionally for faster charging, at 32 amps (providing c. 7kW). Options for drivers to install home charging could include funding support from chargepoint or vehicle manufacturers, or electricity suppliers. Currently the Office for Low Emission Vehicles (OLEV) Electric vehicle homecharge scheme[19] offers individuals who are the registered keeper, lessee or have primary use of an eligible vehicle up to 75%, capped at £500 incl VAT, off the total capital costs of the chargepoint and associated installation costs. Additionally, TfL could include this in any future applications to access funding from organisations such as OLEV or the European Commission.

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[18] It should be noted that the mileage added per 15 minutes is indicative only and does not relate to any specific vehicle.

[19] https://www.gov.uk/government/publications/electric-vehicle-homecharge-scheme-guidance-for-customers-version-20

Public chargepoints can be specified to charge at any of the above rates. Much of the currently available infrastructure in London is 3.5 or 7kW. Faster charging rates are available in certain locations; for example there are 120 22 kW chargepoints within the Source London network located in suburban Underground station car parks and the number of publically available rapid chargepoints is steadily increasing.

Rapid charging

Rapid chargepoints are usually 43kW AC or 50kW DC. In the UK, three rapid charge protocols are in use by mainstream manufacturers:

1. CHAdeMO is primarily used by Japanese vehicle manufacturers, including Nissan and Mitsubishi, as well as Citroen, KIA and Peugeot

2. Mennekes (Type 2) is the recommended standard for public 3.5 and 7kW chargepoints. It can also be used for fast AC charging at 22kW or rapid AC at 43kW. Renault uses this connector for rapid charging the Zoe.

3. Combined Charging System (CCS or Combo) is currently used by BMW and Volkswagen. Most American and European manufacturers, including Ford, General Motors and Porsche have indicated that they will use CCS.

Carrying a charging cable in the vehicle is only necessary when using AC public chargepoints which deliver no more than 22kW. Rapid chargepoints have a tethered cable.

Rapid chargepoint incorporating all three protocols

Choice of rapid charge protocol

For fast and rapid charging rates (typically 20 kW and above), there are two solutions:

- Use a charger built into the vehicle to charge from a 400 volt three-phase AC supply, usually delivering 22kW or 43 kW. An in-vehicle charger converts the alternating current (AC) to direct current (DC) to charge the battery.
- Include an external charger in the chargepoint to convert AC into DC. This typically delivers 20kW or 50kW, although some vehicles, for example those manufactured by Tesla, can be charged at higher power.

For a given power, there is no significant difference in charging time between using an AC or a DC supply. However, when faster charging is required, AC has limitations compared to DC:

- AC supply must be converted to DC to charge a battery, either in the chargepoint or in the vehicle. It is generally more cost-effective to install an AC to DC converter in the chargepoint than to install one in every vehicle.
- AC converters add weight to vehicles and more powerful converters may be larger and heavier, increasing energy consumption slightly and taking up valuable space. A significant amount of heat may be generated, requiring energy to be consumed cooling the charger.

Rapid charging from an AC supply, therefore, has potential cost and in-vehicle energy efficiency drawbacks. Conversely, high voltage, high current DC charging does not face any practical obstacles. Tesla have demonstrated that charge rates in excess of 120kW are possible and it is likely that vehicle charging rates will increase to 150 kW or more in the next few years. Plans for a chargepoint network should take future increases in charging rate into account.

Power output

DC charging is usually delivered at 20kW (fast) or 50kW (rapid). It is potentially easier to find locations with suitable grid capacity to install 20kW chargepoints, and they are approximately half the cost of 50kW chargepoints (for a single outlet chargepoint this could be around £13,000 rather than approximately £25,000). However, depending on factors including the vehicle's current state of charge, it takes roughly twice as long to deliver the same amount of power from a 20kW point compared to a 50kW point.

For some plug-in vehicle users, this might not be an issue. However, as this report will discuss, any charging solution for taxi drivers must minimise changes to their behaviour and working patterns. Since most drivers in London tend to stop for short breaks (15 minutes or fewer), faster charging rates will be required to provide a significant increase in vehicle range.

Additionally, it is important that the network is future-proofed in readiness for technological developments in the market. As vehicle battery capacities increase over the next few years, rates of charge below 50kW may become outmoded.

In summary, we recommend that a dedicated network to support the introduction of plug-in taxis uses 50kW DC chargepoints compatible with both CHAdeMO and the Combined Charging System, with 22kW AC chargepoints used in central areas, perhaps on taxi rest ranks, where the installation of the larger chargepoints is not possible. In these locations twin outlet AC chargers could provide charging for two vehicles (depending on the parking arrangement). If available, units with a type 2 tethered cable and a type 2 socket would provide infrastructure for any vehicle configuration while providing the majority of drivers with a more convenient tethered cable solution.

Safety

We recommend that equipment and installation standards should be mandated for the network operator(s). An example is "Annex D-Minimum technical specification for rapid chargepoints" required by OLEV[1] for rapid chargepoint grants. These include:

- It is required that the final installation will be in accordance with the current edition of the IET Wiring Regulations (BS 7671), the IET Code of Practice (CoP) for Electric Vehicle Charging Equipment Installations, Electricity Safety, Quality and Continuity Regulations 2002 and all other applicable standards.
- Charging equipment shall be compliant with:
  - BS EN 61851 Parts 1 & 22
  - EC Directive for Electromagnetic Compatibility 2004/108/EC
  - EC Directive for Low Voltage Equipment 2006/95/EC
  - BS EN 61851 Part 23 when published.
  - Charging equipment shall be CE marked in accordance with EC Directive 93/465/EEC.
  - AC or DC charging equipment shall utilise a tethered cable (BS 61851:1 Case C connection).
  - Charging Equipment integral protective device required to comply with BS EN 61851 Mode 3 charging shall be Type A RCD.
  - Where installed in an outdoor location, the charging equipment shall meet the minimum IP ratings set out in BS EN 61851:1.
  - The design of the charging equipment shall permit compliance with the requirements of BS 8300: 2009 + A1:2010.

[1] Technical specifications supplied by Ove Arup & Partners Ltd

Concerns have been raised about on-street rapid chargers and the risks posed from these being hit by vehicles, with critics arguing that they should therefore be installed at off-street locations. There is a risk that a rapid chargepoint could be hit by a vehicle, though a crash guard should be installed to minimise this risk. If the concern is that there is an electrical risk, we have discussed this with chargepoint manufacturers who state that equipment will disconnect from the supply in the event of an accident and that there is no risk from this factor. Safety measures to prevent trip hazards and impact by vehicles driving into the equipment are covered in section five.

03 Taxis drivers’ survey and implications for rapid charging

Introduction

To prepare for the introduction of plug-in taxis and ensure that suitable charging infrastructure is available, it is crucial to understand how drivers use their current vehicle, including:

- When do taxi drivers work and how many hours do they spend working?
- How many miles do they cover during a typical shift?
- How far do they travel from their home location?
- Where do they drive and which ranks do they use frequently?
- Where and for how long do they stop for breaks?
- What are their attitudes towards plug-in and electric vehicle technology?

This information can help to estimate how many rapid chargepoints will be required and where they should be located and to assess the challenges which must be overcome before zero emission capable taxis are introduced. This information will form the basis of a chargepoint network for early adopters of plug-in taxis. As network coverage increases spatially, drivers with more varied working patterns can be confident that they will always be within range of a chargepoint.

Taxi drivers’ survey

Licensed taxi drivers were asked to complete a short survey about their working patterns, working hours, areas covered and where breaks are taken. The survey was conducted online and publicised using the following channels:

- Electronically to taxi drivers with email addresses in TfL’s licensing database
- Via the Licensed Taxi Drivers Association, London Cab Drivers Club, Unite the Union and selected taxi booking companies
- Promoted in Call Sign, the in-house magazine for Dial-a-Cab.

Approximately 6,000 drivers were directly invited to take the survey and more were invited indirectly, for example via their trade associations. 672 drivers self-selected to take part, with more than 500 respondents completing the full survey.

Taxi drivers’ working patterns are highly variable as they have autonomy to choose their own hours and the number of trips they make each day. Additionally, the areas of London they cover are to some extent determined by their passengers’ journey destinations. However, a significant majority do have preferred working patterns, regular ranks and commonly visited break locations.

Drivers' survey results: working patterns and implications for a rapid charge network

The following analysis of taxi movements and recommendations around chargepoint infrastructure focuses on the All London drivers who tend to work primarily in central London. Generating the spatial coverage necessary for Suburban drivers will require the installation of a large number of chargepoints, and providing this from day one would leave many chargepoints under-utilised at first. Similarly, chargepoint network operators are likely to focus on central London initially, to be confident of securing a return on their investment.

Four aspects of drivers' working patterns were investigated:

1. Mileage covered (commuting and working)
2. Shift patterns and durations
3. Taxi movements, including frequented ranks and break locations
4. Locations where taxis are kept between shifts

Mileage covered (commuting and working)

The mileage covered by taxis, and therefore the effective vehicle range required (including opportunity rapid charging), is arguably the most important factor in planning a chargepoint network for plug-in taxis. It is vital that plug-in vehicles do not restrict the distance that individual drivers wish to cover.

	Working mileage	Commuting and working mileage
Average	**71**	**98**
Proportion of sample who cover more than 40 miles per day	75%	87%
Proportion of sample who cover more than 60 miles per day	55%	79%
Proportion of sample who cover more than 80 miles per day	30%	64%
Proportion of sample who cover more than 100 miles per day	11%	39%

Average and threshold mileages

- The sample mean shift consists of a 30 mile round trip commute and just over 60 miles driven while working.
- One fifth of All London taxi drivers cover more than 120 miles per day on average.

Shift patterns and durations

Drivers' average shift duration is eight hours and they typically work 38 hours per week. By comparison, the equivalent figures from previous research commissioned by TfL[20] were eight and 40 hours respectively.

1. **Shift start and finish times**

- During the week (Monday to Thursday), drivers most frequently start working either between 6am and 10am or between 2pm and 6pm, and finish between 10pm and 2am.
- On Fridays, drivers' start times follow the pattern observed on Monday to Thursday. While a significant proportion finish work in the early evening, the majority finish working between 10pm and 4am.
- On Saturdays, drivers tend to start and finish working later, with the most common start times between 2pm and 6pm, and the most common finish times between midnight and 4am.
- Finally on Sunday, drivers' start times are spread out between 10am and 4pm, while their shift finish times are evenly distributed through the late afternoon and evening.

2. **Shift duration**

- Before starting work:
  - 42% of drivers commute for less than half an hour
  - A further 42% commute for between half an hour and one hour
  - 13% commute for an hour or more.
- After work:
  - 34% commute for less than half an hour
  - 47% for half an hour to one hour
  - 17% for an hour or more.

This variation between pre- and post-work commute times is likely to be because drivers have little control over where their last fare may take them (none if the journey is below 12 miles) which typically leaves them with a longer journey home than their starting commute. Charging infrastructure operators and vehicle manufacturers need to consider the requirements of drivers, particularly if pure-EVs meeting the London conditions of fitness become available, who will need sufficient range to commute home, or access to a rapid chargepoint.

It is crucial that chargepoint infrastructure allows drivers to cover the shift durations and mileage to which they are accustomed, without excessive downtime increasing the length of their working day. Rapid charging could meet this requirement and allow drivers to be flexible in how they manage their vehicle's charge. For example, they may prefer to combine a longer break with a full recharge, or have two or three shorter top-ups when and where convenient.

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[20] Taxi/PHV Diary Survey 2009. Provided by GfK Consumer Services, January 2010

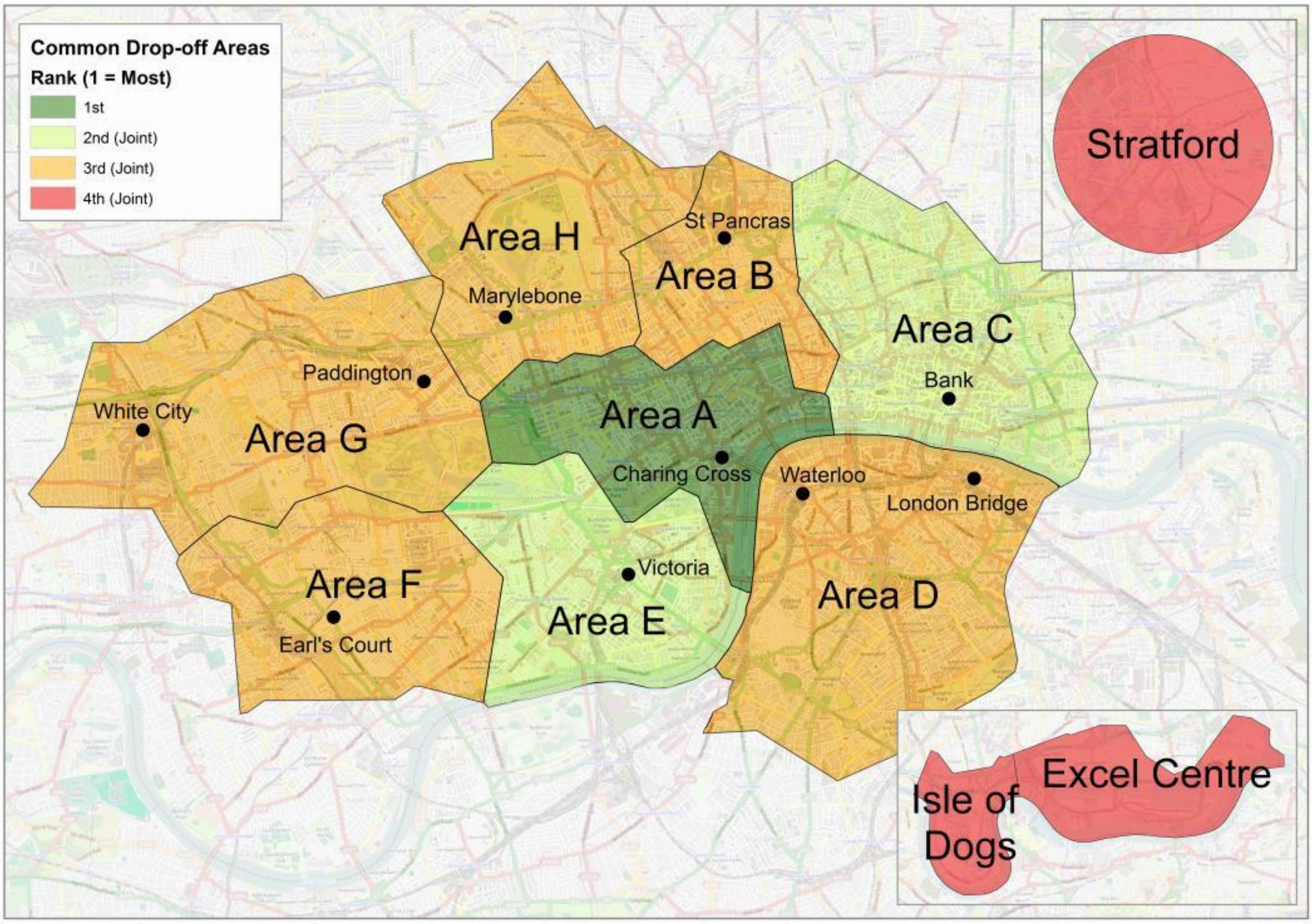
Taxi movements, frequented ranks and break locations

Prior to this study, little research had investigated where taxis operate and where drivers tend to rank. The information gathered included:

- The areas of central London in which drivers most frequently drop off passengers. Other than during a scheduled break or while waiting on a rank, immediately after completing a journey is likely to be the best time to top up the battery.
- The ranks that drivers use most often, particularly at locations such as stations and airports where they may be waiting some time, and therefore there could be an opportunity to recharge a plug-in vehicle.
- The locations where drivers frequently take breaks, which would allow recharging to be integrated into their working pattern with limited behavioural change.

1. Drop-off locations

Survey respondents were presented with a map of Central London divided into eight areas, plus the Isle of Dogs, Excel Centre / City Airport and Stratford. Drivers were asked to select the areas in which they most frequently dropped off passengers. The results are shown on the map below:



Frequent drop-off areas in central London

- Area A, covering the West End, was the most popular with 54% of respondents selecting this as the area where they most frequently drop off fares.
- C (the City and Angel), and E (around Victoria Station) had an approximately equal share.
- Passengers are far less frequently dropped off in the remaining central London areas and three outlying zones.

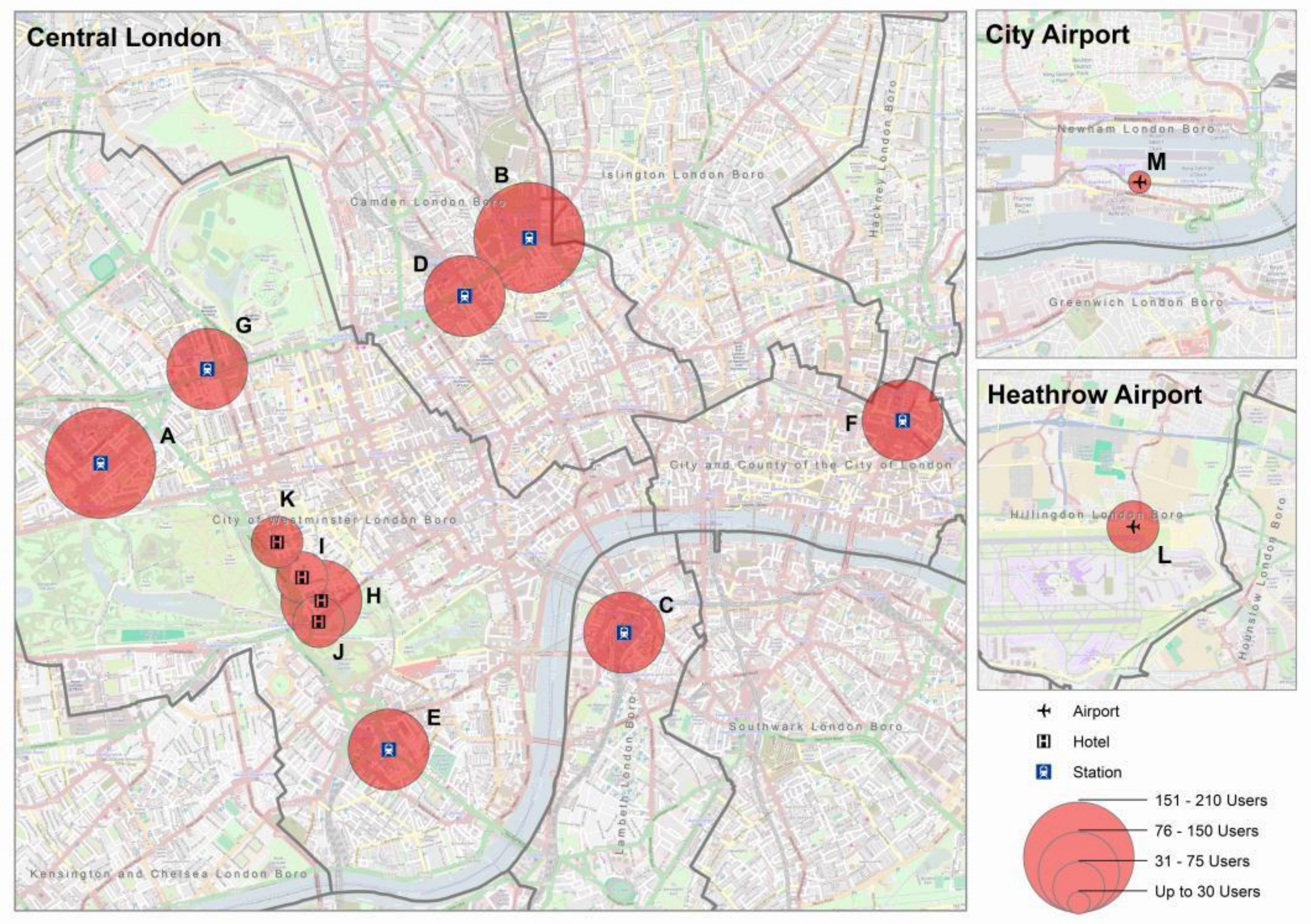
2. Ranks

Survey respondents were asked if there are any ranks (including airports, stations or hotels) which they use on a daily basis

Regular rank used	Proportion of sample
Yes	68%
No	32%

Drivers who have ranks they use regularly

Next they were asked to identify the ranks they use most frequently. The results are shown on the following map with the size of the red circle indicating the number of drivers who use each rank.



Frequently used ranks in central London

The ranks displayed on the map are:

- Stations:
  - Paddington (A), King's Cross / St. Pancras (B), Waterloo (C), Euston (D), Victoria (E), Liverpool Street (F), Marylebone(G).
- Hotels:
  - In W1 postcode area.
- Airports:
  - Heathrow (L), London City (M).

3. Break locations and duration

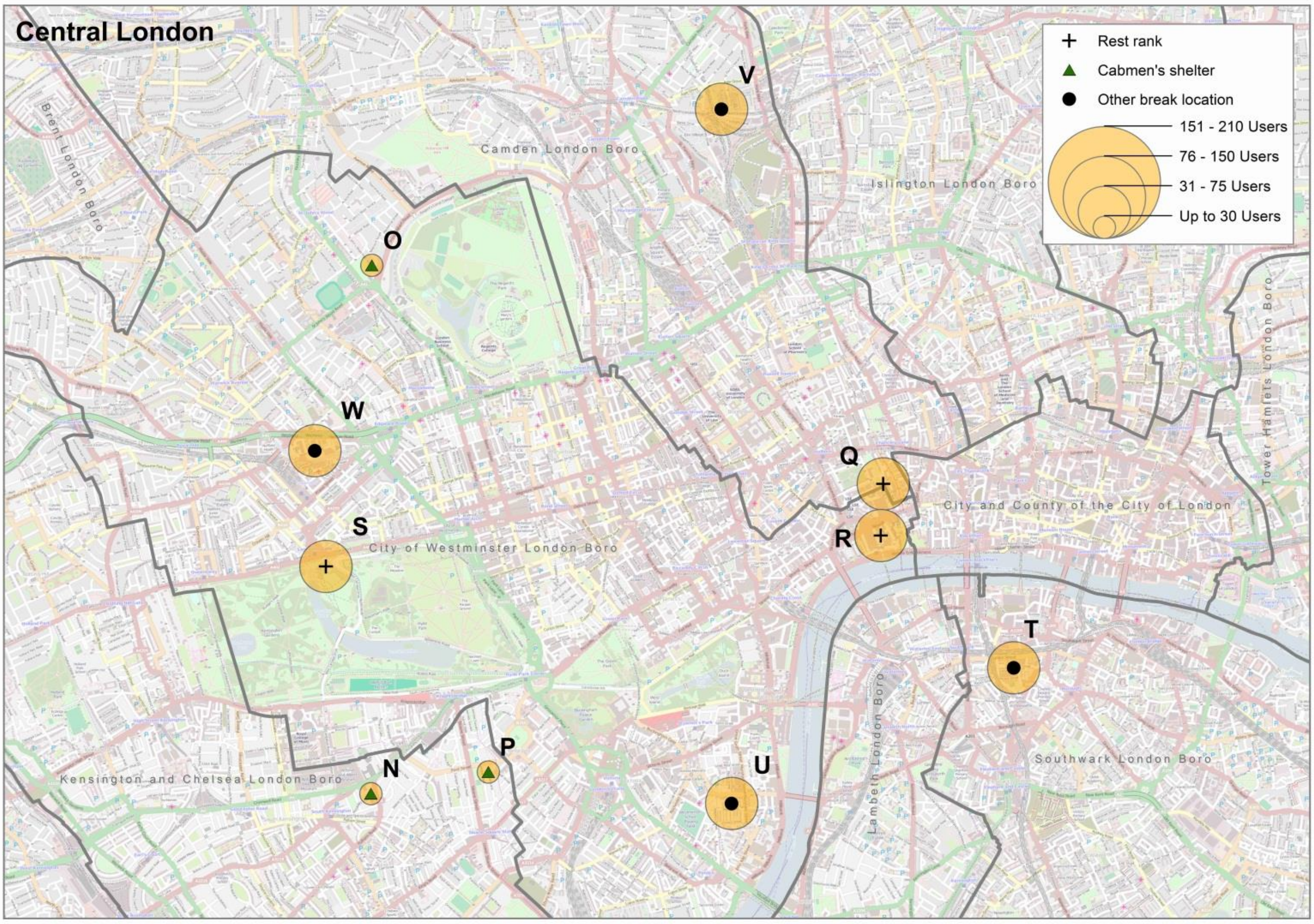
Ensuring chargepoints are available where drivers take breaks, and matching the speed of charge with the length of time they are usually off the road, are essential to minimise the impact that plug-in taxis will have on their schedules. Survey respondents were presented with a choice of sites and asked to specify how long they stopped for at each. The results are shown in the tables below:

	Refreshment (Cabmen's) shelter	Rest, station or other rank	Petrol station	Supermarket / retail / fast food
Do not use	72%	45%	67%	66%
1 – 15 minutes	**12%**	**25%**	**29%**	**23%**
16 – 30 minutes	8%	20%	4%	8%
31 – 45 minutes	5%	8%	1%	2%
46+ minutes	4%	3%	0%	1%
	On-street parking	Airport	Cab café / restaurant	
Do not use	46%	83%	43%	
1 – 15 minutes	**26%**	**2%**	**17%**	
16 – 30 minutes	16%	3%	19%	
31 – 45 minutes	8%	1%	10%	
46+ minutes	4%	11%	12%	

Drivers' break locations and durations

- 46% of drivers who use one of these locations regularly stop for 15 minutes or fewer. Therefore chargepoints should provide a rapid rate of charge so that drivers can top up the battery without additional downtime.
- The exception is "cab café / restaurant", where drivers are more likely to stop for up to half an hour. Therefore these locations, which include cafes at Great Suffolk Street, Camley Street and Paddington Basin, would be an ideal place to locate chargepoints where drivers can fully recharge their vehicle, while accessing toilet and refreshment facilities.
- The data suggests a correlation between daily mileage and break duration. The average mileage for all drivers was 98 miles per day. For drivers who break for more than a quarter of an hour, the average mileage was higher, at 119 miles per day. This suggests that drivers should be able to fit in additional charging time without spending more time off the road.

The locations where drivers most frequently take breaks are shown in the map below:

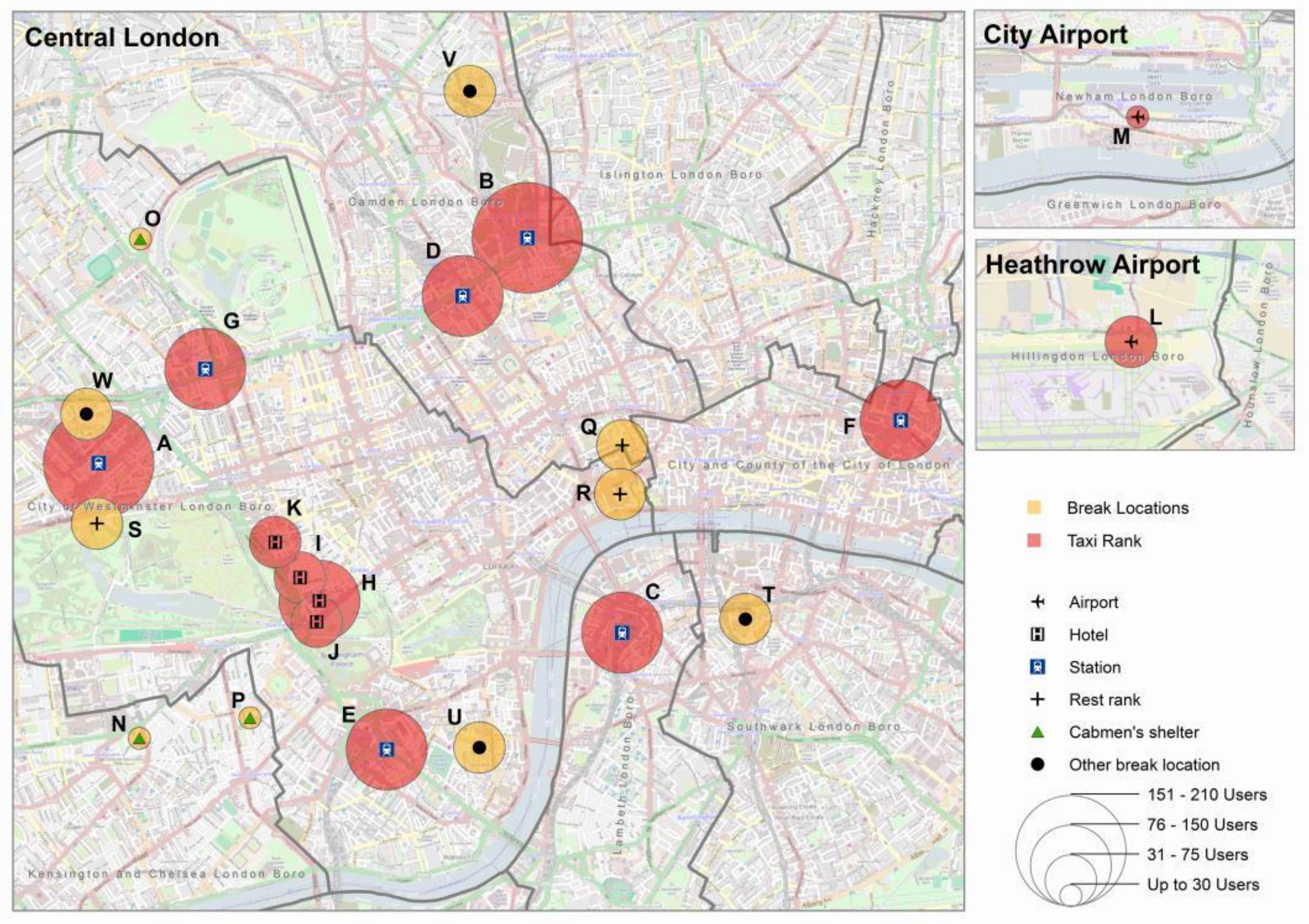


Frequent break locations in central London

The break locations displayed on the map are:

- Cabmen's shelters:
  - Thurloe Place SW7 (N), Wellington Place NW8 (O), Pont Street SW1 (P).
- Rest ranks:
  - Lincoln Inn Fields WC2 (Q), Strand WC2 (R), Lancaster Gate W2 (S).
- Other locations:
  - Great Suffolk Street SE1 (T), Horseferry Road SW1 (U), Camley Street King's Cross (V), North Wharf Road near Paddington (W).

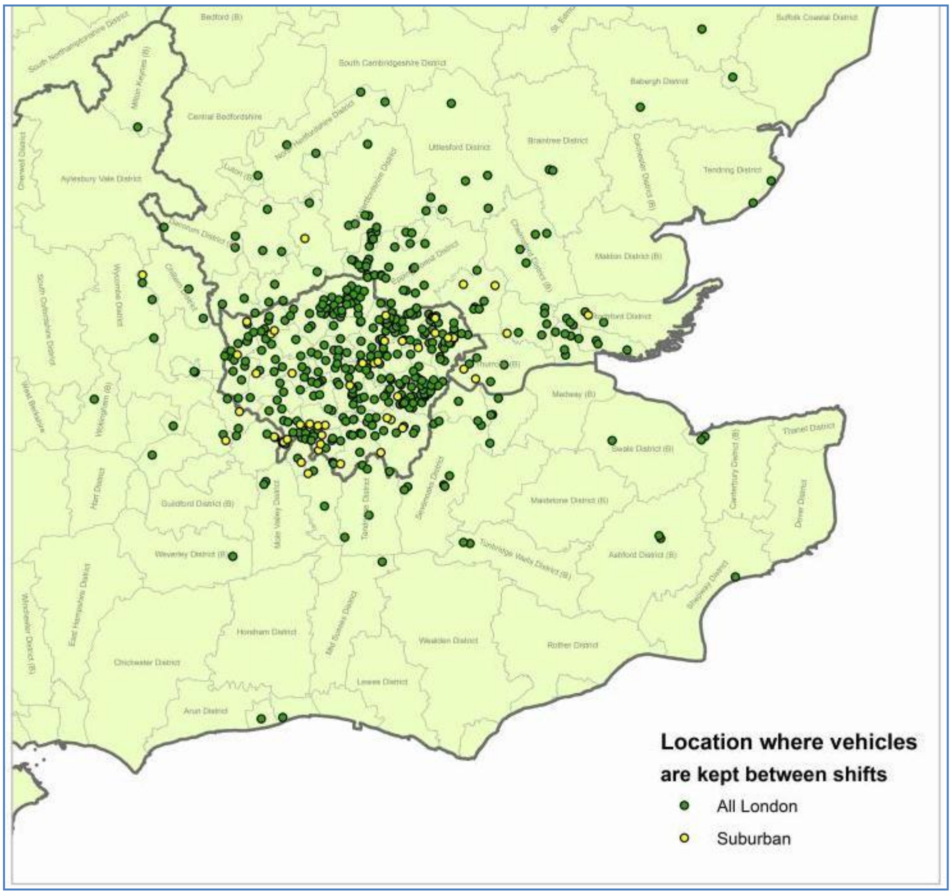
The map below combines rank and break locations to show sites in London where taxis frequently stop.



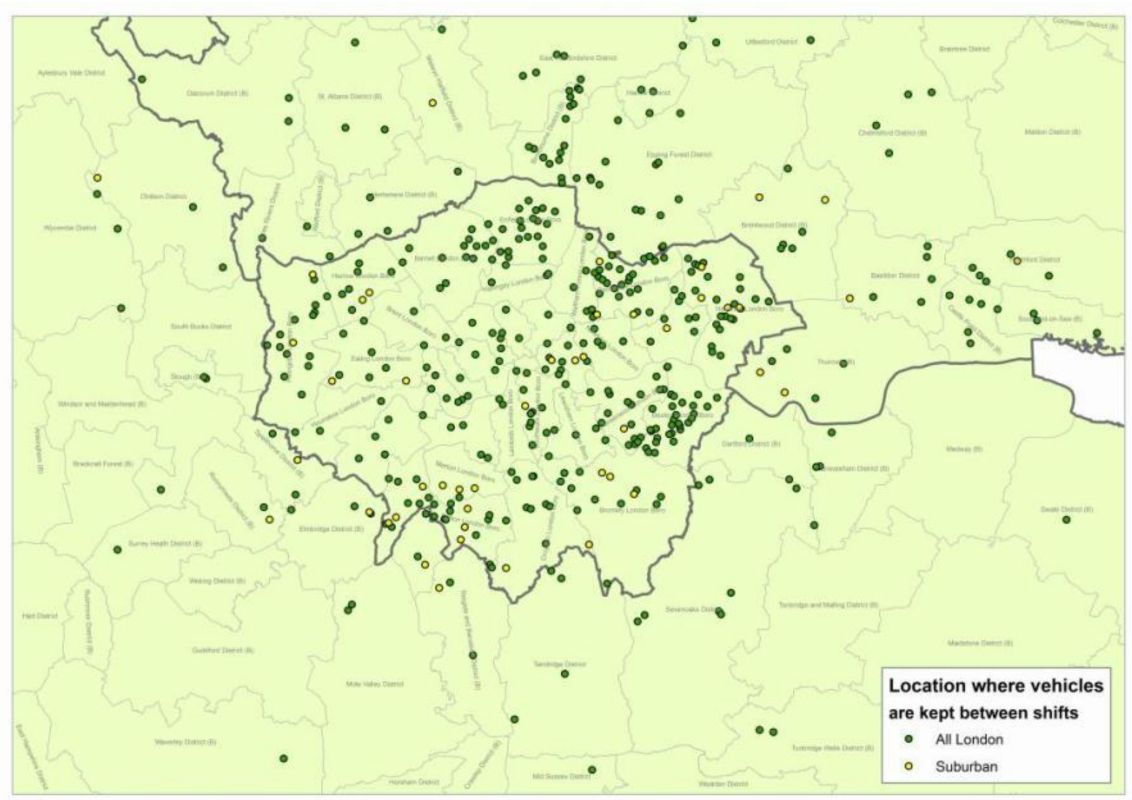
Common rank and break locations

Locations where vehicles are kept between shifts

91% of survey respondents were All London drivers, licensed to operate anywhere in London, with 9% Suburban drivers. The maps below show the locations where vehicles are kept between shifts (green dots indicate All London and yellow dots indicate Suburban drivers). This indicates a wide spread of locations across inner London and the suburbs, as well as a significant proportion who live outside Greater London.

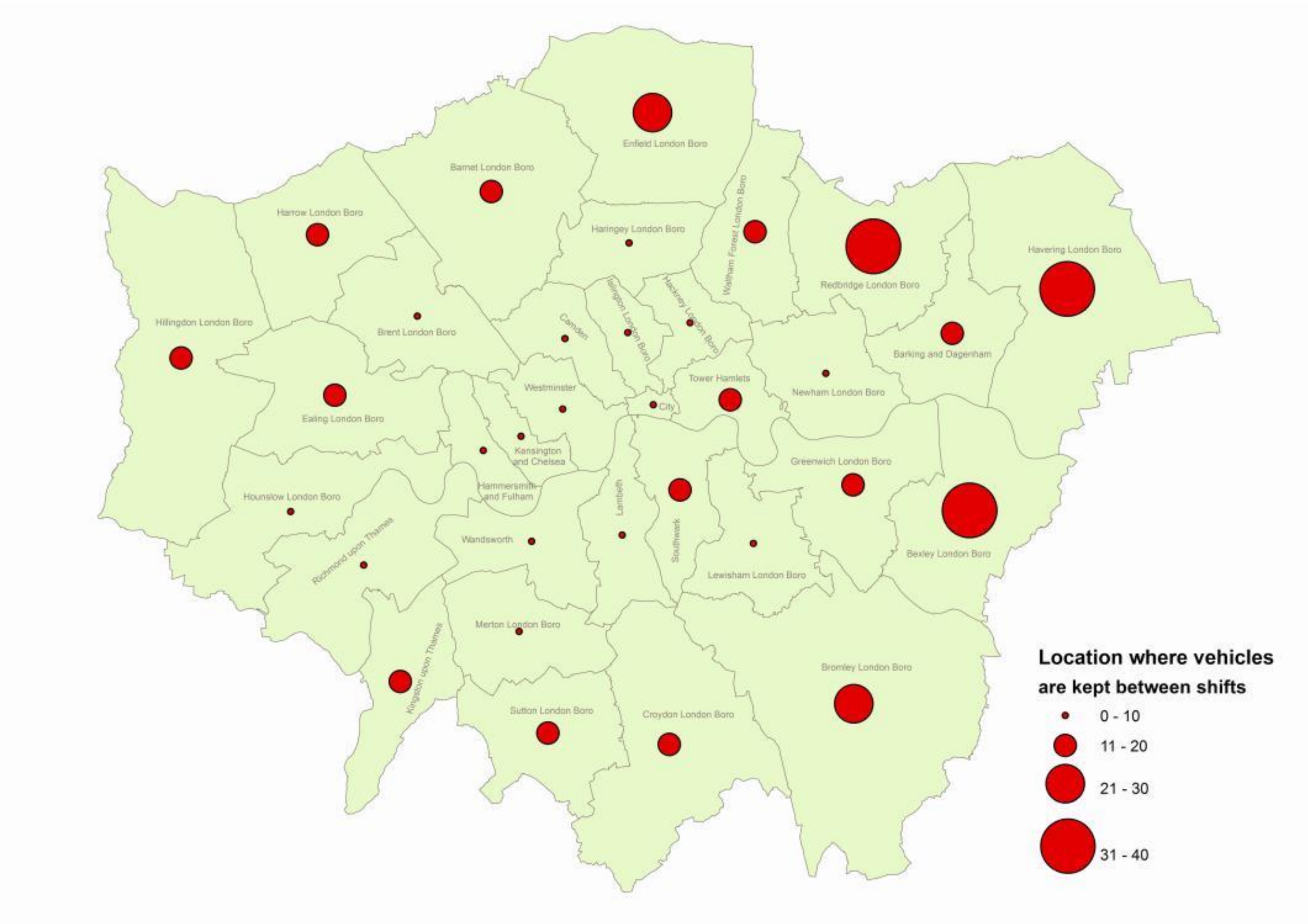


Vehicle locations (regional)



Vehicle locations between shifts (London)

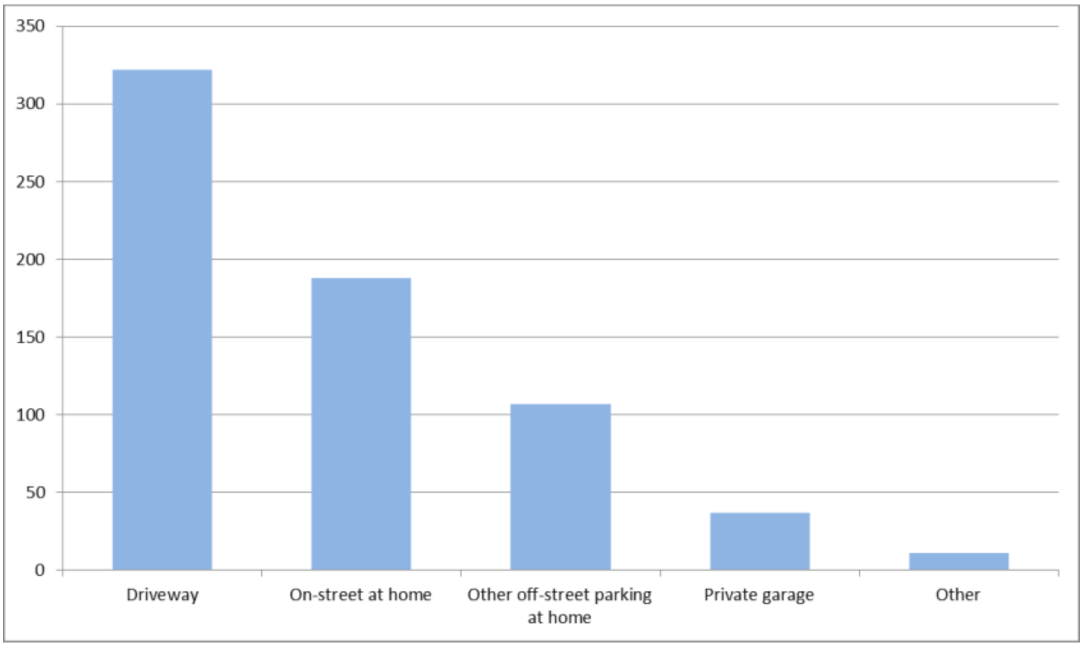
The map below shows where taxis are kept between shifts within London, disaggregated by borough.



Vehicle locations between shifts by borough

The map indicates more vehicles are kept in locations in north east, east and south east London. As discussed, our recommendations for early chargepoint infrastructure focus on central London. Once the network expands into the suburbs, this spatial distribution of vehicle locations should be considered. For example, more chargepoints may be required between central London and the eastern side of the city than to the west.

The majority of drivers who acquire a plug-in taxi will want to recharge it at home and will therefore need to be able to have a chargepoint installed. As the graph below shows, most drivers who responded to the survey (70%) leave their vehicle on their driveway, parked off-street or in a garage between shifts. A significant number of these drivers should be able to have a chargepoint installed, however the provision of between shift charging infrastructure should be investigated for drivers with no opportunity to park off road. The vehicle locations between shifts by borough map above could be used to prioritise the installation of infrastructure suitable for these drivers within a reasonable walking distance from home.



Where vehicles are kept between shifts

The provision of rapid chargepoints on major routes into central London would also provide opportunities for these drivers and those living outside London to recharge during their commute. These chargepoints could be more widely available for use by the private hire trade and commercial vehicle operators. Research carried out for TfL by the Energy Saving Trust identifying suitable locations for such infrastructure should be considered.

Chargepoint network overview

Plug-in taxis and private hire vehicles[21] will both require broadly the same type of supporting infrastructure in similar locations in central London and at key transport hubs. However, a dedicated network of chargepoints should be provided for the exclusive use of (Hackney) taxi drivers. There are three reasons behind this recommendation:

1. From 2018, all newly licensed taxis will have to be zero emission capable and therefore the chargepoint network will have to grow rapidly. Installing sufficient chargepoints will be challenging, and would be made more so if capacity for other users were included.
2. Many of the illustrative chargepoint locations for taxis are on sites where they have exclusive access, such as refreshment ranks or rest ranks. Clearly these lend themselves to a dedicated taxi network.
3. Finally there is already competition between the taxi and private hire markets and limited co-operation. Attempting to introduce a potentially disruptive technology that both trades

[21] From 1 January 2018, subject to public consultation, all new vehicles (less than 18 months old from date of first registration with DVLA) presented for licensing as a PHV for the first time will need to be ZEC. ZEC means ≤50g/km of CO_2 and minimum zero emission range of 10 miles or >50 g/km and <75g/km CO_2 and minimum zero emission range of 20 miles. Vehicles licensed to carry seven passengers would not need to meet the ZEC requirement until September 2020.

have to compete for the use of is unlikely to facilitate a smooth transition to the use of plug-in vehicles in these fleets.

We recommend that most chargepoints installed are:

- 50kW, to minimise downtime and disruption to drivers and facilitate a greater number of charging events per post per day.
- DC, a better solution than AC for faster charging rates (as discussed in section two).
- Compatible with both Combined Charging System and CHAdeMO protocols, unless agreement is reached by the vehicle manufacturers on a single protocol.

Scale of the network

Based on the information gathered regarding where taxis work, how long they drive for (in time and mileage), where they rank and where they take breaks, estimates of the number of chargepoints required can be made, and illustrative locations proposed.

The number of chargepoints required depends on numerous variables including:

- The number of rapid charge compatible, zero emission capable taxis which will be acquired per year.
    - In addition to the baseline churn of the fleet due to the current age limit, accelerated uptake due to the appeal of the new vehicles and/or the additional incentives available to vehicle owners may increase vehicle deployment.
    - It is anticipated that most plug-in taxis will be rapid charge compatible, but it has not been confirmed that all manufacturers are currently developing vehicles which include this technology.
- The average mileage driven by the early adopters of zero emission capable taxis.
- The relative market share of pure-EV and E-REV taxis (both technologies may not be available from 2018).
- The proportion of mileage which E-REV drivers will cover on electric-only power (rather than simply using the petrol engine once the battery is depleted). This could easily be overlooked and TfL should consider how to ensure drivers use E-REVs appropriately.
- The vehicles' energy consumption (Wh/km).
- The proportion of electric-only mileage which will be supported by opportunity (rapid) charging rather than home or depot charging.
- Additional (and theoretically unnecessary) opportunity charging events which drivers will utilise to keep their battery topped up. Many drivers will want to maintain a high level of charge throughout their shift, especially while they are getting accustomed to the new technology.
- The number of charging events that will take place per chargepoint per day.

Scenario modelling

We assume that:

- Average daily working and total mileage will be 71 and 98 miles respectively, as per the survey results.
- E-REV drivers will use electric power for all working mileage and ICE power for commuting
- Pure-EV drivers will charge up 25 miles more than they drive each day.
- Vehicles will have an approximate energy consumption of 210 Wh/km
- A 50 kW chargepoint will deliver 10 kWh in 15 minutes
- Each chargepoint will deliver 20 charging events per day; we understand from our discussions with industry experts that this is a high yet achievable figure

Putting all of this together, the forecast chargepoint numbers by the end of 2018 for each scenario are as follows:

Therefore we forecast that by the end of 2018 approximately 90 50kW DC chargepoints will be required. We estimate that installing approximately half of these (45) by 1 January 2018 would likely be sufficient to give drivers confidence in the development of the network. This would support the introduction of 1,400 taxis, based on the current replacement cycle of the vehicles. Additional financial support being made available to drivers by TfL, in particular a voluntary decommissioning scheme, and the increase in replacements typically seen when a new vehicle is launched is anticipated to lead to the following scenarios:

Scenario	Number of chargepoints (2018)
1 Baseline, 50% E-REV	88
2 Baseline, 100% E-REV	73
3 Accelerated uptake, 50% E-REV	150
4 Accelerated uptake, 100% E-REV	126

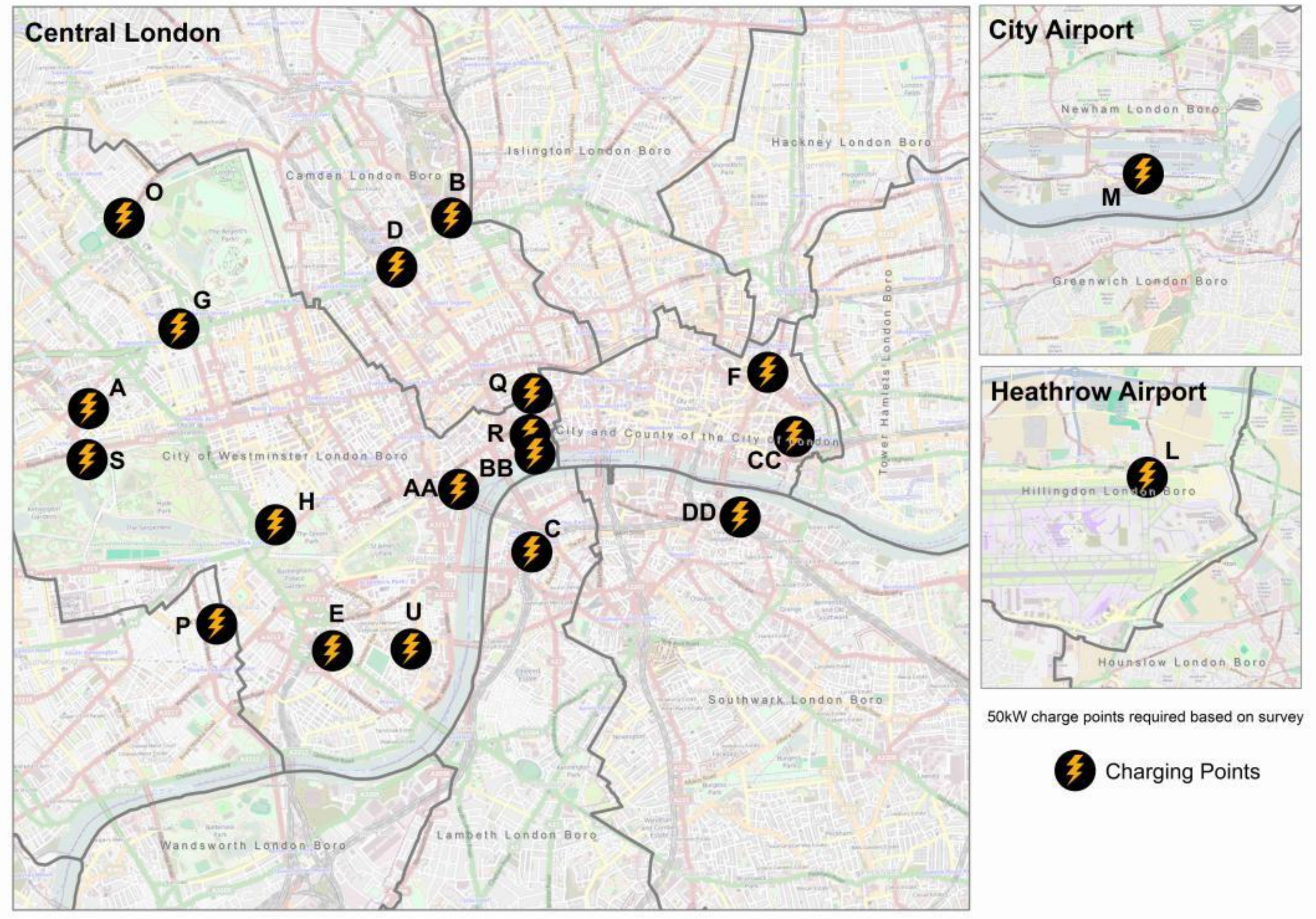
We would suggest that in central areas, where it is not possible to install rapid chargepoints, that two 22kW chargepoints are substituted for each rapid. Once again, these figures should be treated with caution, bearing in mind the caveats listed earlier. Should all the vehicles be E-REV which is anticipated in the early years following 2018, then the 50% E-REV figure for chargepoint numbers would apply assuming approximately half of the drivers both commute and work in electric drive mode.

Chargepoint locations

Determining suitable locations for the chargepoints will be critical to the success of a rapid charge network for two reasons:

1. Drivers must be able to find chargepoints in the areas where they work or at locations near where they rank or take breaks.
2. Utilisation rates will be higher for strategically located chargepoints, increasing revenue for the network operator.

The map below shows illustrative locations based on the rank and break data from the drivers' survey.



Illustrative chargepoint locations (part 1)

- Stations:
  - Paddington (A), King's Cross / St. Pancras (B), Waterloo (C), Euston (D), Victoria (E), Liverpool Street (F), Marylebone(G), Charing Cross (AA), Fenchurch Street (CC) and London Bridge (DD).
- Hotels:
  - In W1 postcode area.
- Airports:
  - Heathrow (L), London City (M).

- Cabmen's shelters[22]:
    - Wellington Place NW8 (O), Pont Street SW1 (P), Temple Place WC2 (BB).
- Rest ranks:
    - Lincoln Inn Fields WC2 (Q), Strand WC2 (R), Lancaster Gate W2 (S).
- Additional break location:
    - Horseferry Road SW1 (U).

In order to provide the forecast number of chargepoints (c.90) in and around central London between one and three chargepoints should be installed at or at a reasonable distance from each location. The exact number to be installed at a given site will depend on the results of Distribution Network Operator surveys to establish local grid capacity.

In addition to these sites, chargepoints should be made available to ensure that the network is prepared should central London become a truly zero emission space in the future. Drivers would need to be certain that they will have sufficient electric power when approaching or working within a zero emission zone.

Three locations were identified from the survey, where taxi drivers frequently take breaks:

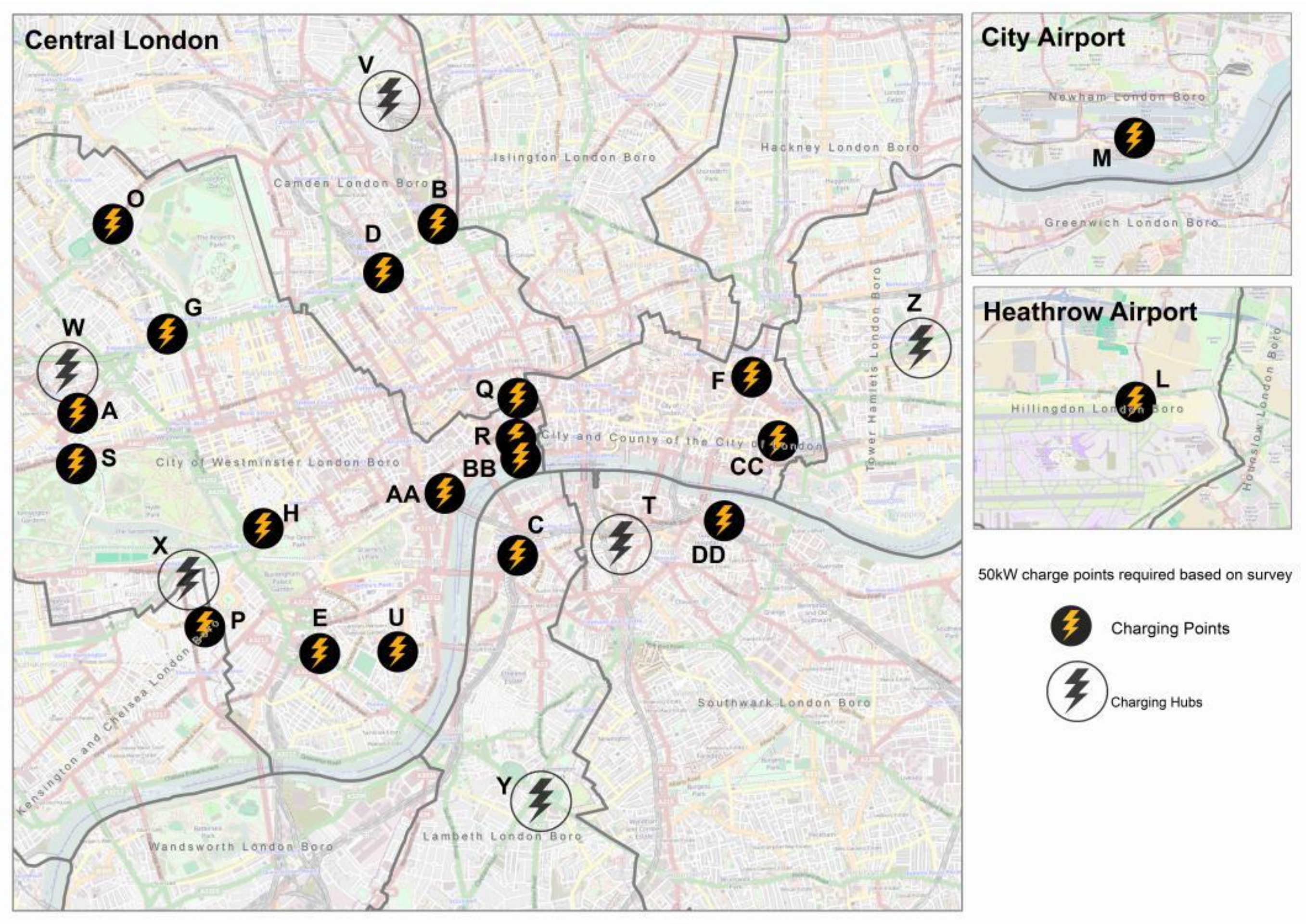
- Taxi drivers' café on Camley Street near Kings Cross.
- Disused Texaco Garage on Great Suffolk Street.
- Royal Oak taxi café, Paddington Basin.

In addition, three more locations would give reasonable spatial coverage around central London. Possible locations, purely chosen to give appropriate geographic coverage, would be:

- Whitechapel Station (end of the A11)
- Oval Station (end of the A3)
- Knightsbridge Station (end of the A4).

These six locations, added to the previously identified sites, are displayed on the map below.

[22] Note that the Thurloe Place shelter was excluded as it is in the middle of the road and therefore not suitable for hosting a chargepoint.



Illustrative chargepoint locations (part 2)

- Additional locations:
    - Great Suffolk Street SE1 (T), Camley Street King's Cross (V), North Wharf Road near Paddington (W), Hyde Park Corner (X), Oval / Kennington (Y), Whitechapel (Z).

These additional six locations have been termed 'chargepoint hubs' because we suggest that as the network grows towards 2020 and beyond, these locations or similar available sites in the vicinity will eventually host more chargepoints than the space-constrained central London sites which may be more suited to 22kW charging.
The relevant Distribution Network Operator will need to carry out site surveys to determine how many chargepoints could be installed at these suggested locations. Therefore it is not possible at this stage to specify the exact number of chargepoints to be installed at individual sites. However, it is proposed that one to four points could be installed at each site to set up a network of 90 chargepoints. If further vehicle uptake analysis or trade engagement identifies that more chargepoints are required in year one, we would advise using the same locations but providing more chargepoints at each.

The illustrative locations identified in this report are based only on the analysis described above and have not been discussed with the land owners, nor have any site assessments taken place. These results have been considered by TfL as part of its wider research and stakeholder engagement activities that together inform the deployment strategy for chargepoints in London.

Timescale and network development beyond 2018

Chargepoints will not be required at all of these locations for the first zero emission capable taxis to be introduced.

- It is estimated that approximately 90 chargepoints will be required by the end of 2018.
- Installing approximately half of these (45) by 1st January 2018 would likely be sufficient to give drivers confidence in the development of the network. Even if this proves to be an over-estimate, it is worth noting that if 90 are needed by the end of 2018 then 45 will only be sufficient for the first half of the year at the most.
- Installing two chargepoints at each of the 20 locations specified above (excluding the 'hub' sites), plus a third at sites with forecast high demand such as Heathrow Airport, might be a sensible starting point, subject to Distribution Network Operator site surveys.
- These initial chargepoints can be targeted at sites which do not require expensive upgrades to the electricity supply, with the remainder installed gradually through that year based on utilisation data.
- At locations such as in central London where rapid chargepoints cannot be installed, we recommend that two 22kW chargepoints (or chargepoints capable of charging two cars at 22 kW simultaneously) are installed for each rapid chargepoint substituted.

Network operator(s) should consider the risk of installing too many chargepoints initially which could lead to low utilisation levels. However, demand for charging will increase rapidly as more zero emission capable taxis are acquired. The risk of under-utilised infrastructure is likely to be lower than with other projects where the ongoing demand is much harder to forecast.

Beyond 2018, there are too many uncertainties for us to accurately forecast the number of chargepoints required. In addition to the variables listed at the start of this section, the estimated number of charging events per chargepoint will become more complex. For the most popular chargepoints, in central London and the airports, it is possible that higher utilisation rates will be achieved. Equally, as the network spreads geographically into the suburbs, some chargepoints will have considerably lower utilisation rates initially. In some areas, a trade-off will develop between providing sufficient spatial coverage and ensuring that average utilisation rates across the network are sufficient to prevent long term cross-subsidisation between sites.

The model described above can be used to generate very rough estimates of the number of chargepoints required in 2020:

- In a scenario where 9,000 taxis were on the road and assuming a 50/50 split of EVs and E-REVs in the fleet, approximately 560 rapid chargepoints could be required across Greater London.

These numbers must be refined based on observed plug-in vehicle uptake rates and analysis of chargepoint utilisation data.

To complicate matters further, the number of vehicles that can be supported per chargepoint should increase through 2019 and 2020, assuming that:

- Utilisation rates (charging events per day at each location) remain high, particularly in central London
- Local electricity supply balancing is implemented at sites with multiple chargepoints
- Energy storage is introduced at sites with multiple chargepoints

It is therefore emphasised that the estimates for 2020 are to be treated as no more than 'ballpark' figures. We strongly recommend that TfL, supported by the network operator(s) collates and monitors utilisation data to determine when and where additional infrastructure is required, using the locations suggested above as a guideline. This is in line with best practice guidance from industry experts. TfL should also work with taxi drivers to identify sites where they would benefit from additional charging infrastructure. At this point, selecting locations where large numbers of taxis already operate arguably matters less than providing good spatial coverage across the capital, including outlying boroughs. As an indication, additional potential sites to consider include:

- Event venues such as The O2, Wembley Stadium, Wembley Arena, the Queen Elizabeth Olympic Park, the Emirates stadium, Twickenham Stadium and ExCeL London.
- At or near marshalled taxi ranks, as well as mainline and underground stations in the suburbs.

As subsequent sections of this report will show, ensuring there is available grid capacity to supply rapid chargepoints is arguably the greatest barrier to be overcome. While only a relatively small number of chargepoints are required initially, preparations need to be made to ensure that the electricity network can cope with the addition of more chargepoints in subsequent years.

Timescale for network introduction

Pre-2018

- Install c. 45 rapid (50kW) DC chargepoints by 1 January 2018, using locations provided earlier as a guide. Re-forecast numbers once more is known about likely vehicle uptake rates
- Provide assistance for early adopters to install a dedicated home charging solution.
- Identify sites where grid capacity exists for additional chargepoints and/or carry out upgrades as required.

2018

- Monitor utilisation rates for each chargepoint, and use this information to add chargepoints to existing sites as required.
- Increase number of charge points to approximately 90 by the end of 2018 (refining the number required appropriately, based on utilisation rates, vehicle uptake etc.).

2019 onwards

- Expand number and geographical coverage of rapid chargepoints across Greater London based on continued monitoring of utilisation rates.
- Continue to plan ahead ensuring that grid capacity can meet demand.

Following the above steps will help ensure that network development is cost-effective and meets drivers' requirements.

- Infrastructure installations and substation upgrades can be planned in advance rather than following a more costly piecemeal approach.
- Chargepoint data management will ensure additional infrastructure is strategically located to meet growing demand and therefore utilisation levels will be optimised.

Price per charge

The cost of acquiring and operating a plug-in vehicle will be among drivers' greatest concerns when shifting to this technology. There are three factors to consider:

1. Plug-in vehicles must cost less per mile in fuel when charged from a rapid chargepoint than a new, efficient taxi would cost to run on conventional fuel. A hypothetical taxi powered by petrol would cost around 16 pence per mile (ppm) for fuel if it returns 35 mpg. (An E-REV taxi with a depleted battery being driven on petrol power may return a figure of this magnitude.) The table below compares this to the cost per mile of using a 50kW rapid chargepoint for a plug-in vehicle with an energy consumption of 210 Wh/km:

Cost per 15 minute charging event	Cost per mile (ppm) on electric power
£3.00	10 ppm
£3.50	12 ppm
£4.00	14 ppm
£4.50	15 ppm
£5.00	17 ppm

Running costs based on use of rapid chargepoints

A fee of more than £3.50 per 15 minute charging event or 30p/kWh is unlikely to offer E-REV drivers an incentive to use electric rather than petrol power. It is crucial that E-REV drivers use rapid charging rather than relying on the petrol engine once the battery is depleted. Ensuring that E-REVs are rapid charge compatible and that the price of a rapid charge is competitive will be essential, but these points by themselves may not be sufficient; TfL must consider the risks associated with these drivers not utilising their vehicles effectively.

2. Even if plug-in taxis are expected to save drivers money based on the total cost of ownership (TCO), the higher upfront purchase or lease cost must not become an obstacle to uptake of these vehicles.

3. Financial incentives which apply to many electric vehicle users in London, such as the 100% Congestion Charge discount and free or discounted parking while using a public chargepoint, will not apply to taxis. Consideration should be given to additional incentives specifically aimed at the trade.

Additional considerations

- Drivers should have the flexibility to charge for as little or as much time as required, and pay per minute or per kW. The exception may be for pre-booked charging slots, where a minimum of, say, 10 minutes may be sensible.
- The majority of drivers surveyed (58%) expressed a preference for a pay-as-you-go (PAYG) model; a solution also favoured by chargepoint operators and OLEV. Specific PAYG options are covered later in this report.
- Diurnal and weekly demand for chargepoints should be considered when developing the network. Charging is likely to take place either side of drivers' peak working times.
- Drivers will expect to access charging when and where it is convenient and not experience problems in finding a chargepoint. This will be particularly important in the early stages of zero emission capable taxis, when drivers' confidence in the new technology must be built up. A few negative experiences at this stage may create a perception problem which would prove very difficult to overcome.
- A balance should be struck between providing sufficient spatial coverage and installing few chargepoints at a large number of sites. Installing more chargepoints at hubs may reduce the total cost of grid upgrades and infrastructure installation, as well as reducing anxiety that chargepoints may be in use or out of service.
- Where chargepoints are installed, they should be incorporated with other facilities such as toilets, particularly at larger 'hub' sites.

Drivers' survey results: attitudes to plug-in vehicles

As part of the survey, drivers were asked how likely they are to consider acquiring a vehicle with different drivetrains when they next replace their vehicle. The results are shown in the table below:

	Diesel	Petrol	Pure electric	Diesel-electric hybrid	Petrol-electric hybrid
Very unlikely	10%	35%	36%	15%	24%
Unlikely	6%	18%	19%	5%	10%
Likely	34%	22%	19%	**37%**	**30%**
Very likely	45%	15%	12%	**33%**	**25%**
Don't know	6%	10%	14%	10%	11%

Attitudes towards different drivetrains

Driver attitudes to plug-in taxis suggest that the technology is likely to be accepted.

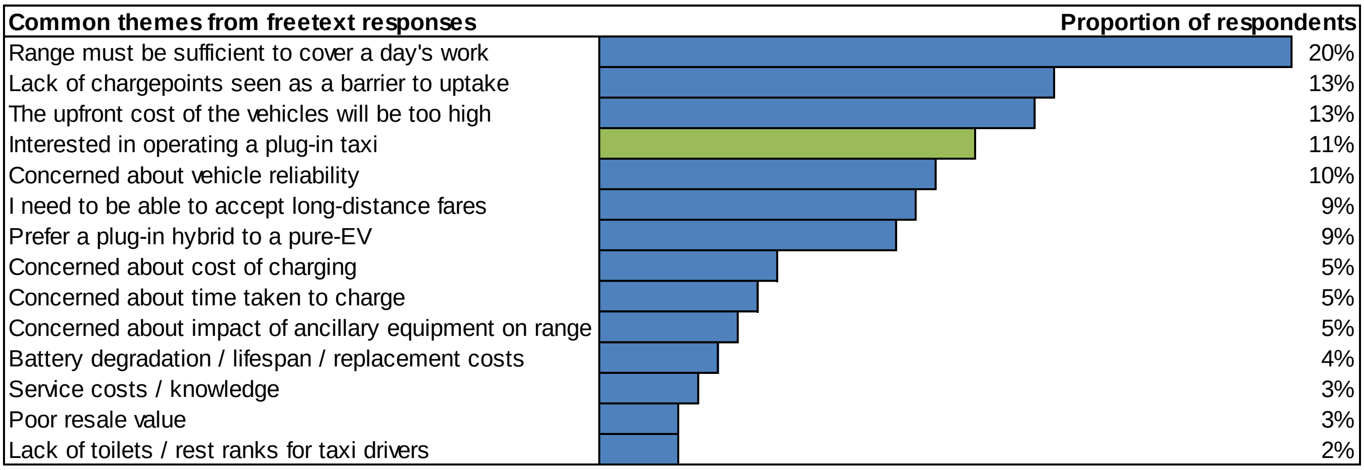
- 70% of respondents are likely or very likely to consider a diesel-electric hybrid when they next replace their vehicle.
- 55% of respondents are likely or very likely to consider a petrol-electric hybrid when they next replace their vehicle.
- 31% of respondents are likely or very likely to consider a pure electric taxi when they next replace their vehicle

Drivers were also asked about their perceived barriers to operating a plug-in taxi, with the results shown below:

Perceived barrier	Proportion of sample
Insufficient range (in miles) between charges)	83%
Concern about running out of charge	80%
Nowhere to charge during shifts	66%
High lease / purchase cost	64%
Charging would impact on my productive working time	63%
I may have to charge too often during a shift	63%
Nowhere to charge between shifts	63%
The technology is new and unreliable	48%
Needing to know where the chargepoints are	42%
None	2%

Perceived barriers to operating a plug-in vehicle

Finally, a free text box was provided for drivers to provide more information about plug-in vehicles. These were categorised and the most popular themes are displayed in the graph below:



Additional comments around plug-in vehicles

Although this illustrates that many drivers have picked out some of the most common objections to plug-in vehicles, such as insufficient range and high upfront cost, it also reveals a positive attitude towards plug-in vehicles among many drivers, with 11% of respondents who provided comments expressing a keen interest in acquiring a plug-in taxi. Where misconceptions exist, TfL and manufacturers should seek to overcome these through communication with drivers, and by providing the support they may require to become accustomed to a new type of taxi.

04 Infrastructure: suppliers and operators

Introduction

The plug-in vehicle market is developing at a rapid pace, not only in terms of the number of vehicles coming to market, but also the charging technology required. UK central and local government continue to support and encourage the development of this market. The result is that there are now almost 12,000 connectors available at 4,240 locations across the country according to Zap Map[23]. Charging infrastructure and plug-in vehicles can be viewed as a chicken and egg scenario. For many, it was considered that consumers wouldn't invest in the new technology without the infrastructure first being in place to provide certainty that a journey could be completed. Many surveys of public perception supported the need for public infrastructure before they would invest in the cars and vans. However the results from long term vehicle trials indicated that this may not be the case. It became clear that most drivers charged predominantly at home and rarely used public infrastructure.

Initially much of the infrastructure installed was based on the three pin (BS 1363) socket, which allows earlier generation vehicles to use the chargepoints as well as the latest models. Since April 2012, only Type 2[24] chargepoints have been eligible for Office for Low Emission Vehicles (OLEV) grant funding; subsequently this has been the most common type of installation.

Much of the early infrastructure was located either where a site could be found, or where it was considered that it might be needed. However, analysis of potential locations was hampered by the small number of plug-in vehicles on the road at the time. Some early installations do not have the capability to be connected to commonly-used back office systems for network management.

Rapid chargepoints are now installed at most service areas on the motorway network and major A roads. *The Road Investment Strategy: for the 2015/16-2019/20 Road Period*[25], published by the Department for Transport (DfT) states that "95% of the Strategic Road Network will have a charging point every 20 miles. Wherever possible, these will typically be rapid charging points that can charge a battery electric vehicle in less than 30 minutes". Rapid chargers are now recognised as an enabling technology, allowing longer distances to be driven without lengthy recharging periods being necessary.

[23] https://www.zap-map.com

[24] The European Commission has given its support to making Type 2 the Europe-wide standard connector for the charging infrastructure for electric cars.

[25] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/408514/ris-for-2015-16-road-period-web-version.pdf

The use of rapid charging will be highly desirable for the successful introduction into London of a fleet of pure electric or extended range taxis. The costs of the infrastructure, its demands on the electricity supply system, constraints on available space and high utilisation rates mean that the network should be planned carefully, managed effectively and be reliable.

Industry perspective: infrastructure suppliers and operators

Scale of installations and charging rates

To determine the technologies available and the costs involved in the installation of charging hardware, software and systems which will be required to deliver the reliability, connectivity and required level of reporting, we interviewed the representatives of five organisations involved in the supply and installation of chargepoint infrastructure. Organisations we spoke with are confident that rapid charging facilities can be installed en-masse and there are examples in other countries, most notably China, of large scale installation and operation of rapid chargers. In Shenzhen c.850 BYD taxis are in operation and one charging hub has 116 80kW DC chargepoints. There are 10 other locations around the city each with 10 chargepoints. Although London faces different challenges to cities like Shenzhen, we believe that concerns about the load plug-in vehicles will place on the grid can be overcome with careful design.

Battery degradation for vehicles routinely rapid charged is now viewed by some vehicle and charging infrastructure manufacturers and chargepoint suppliers as no worse than always charging vehicles at a slow rate. As battery technology improves and costs fall, charging rates are expected to increase. Tesla are installing a network of 120kW “Superchargers” in the United States and Europe which have the capability of charging a 90kWh battery (by way of comparison, a Nissan Leaf has a 24kWh or 30 kWh battery) from 10 per cent to 80 per cent state of charge in 40 minutes.

Charging hardware

Our initial discussions led us to consider 20 kW DC chargepoints, which can provide fast charging rates, are approximately half the cost of 50kW units and there are fewer restrictions on the locations they can be installed as they require fewer upgrades to the electricity supply. However the number of chargepoints which will be required for London’s taxi fleet means that the electricity distribution network may need substantial reinforcement. The costs estimated by UKPN at the sample survey locations considered suggest that there is no direct correlation between the power required for chargepoint installation and the cost of uprating the electricity supply or installing a substation. 50kW DC chargepoints will provide an adequate recharge rate and minimise downtime for the driver, which will be critical as the number of zero emission capable taxis in the fleet increases.

It is unlikely that a common rapid charging protocol will be agreed between all vehicle manufacturers; however it will be desirable to restrict this to the two DC protocols: CHAdeMO and Combined Charging System (CCS) for the taxi network. Rapid charging from an AC supply has cost and in-vehicle energy efficiency drawbacks. Conversely, high voltage, high current DC charging does not face any practical obstacles. For more information about the relative merits of DC and AC charging, please refer to section two.

It is feasible to install chargers which will supply two vehicles simultaneously and to install units which separate the user interface and the power module. The recharging units are smaller and have less impact on the streetscape and the power modules can then be installed in a less sensitive position.

Reliability

The need for hardware to be reliable was emphasised by all suppliers and operators and there are concerns in the industry that some units currently in service have a poor record in this regard. It is important therefore that the installer and/or operator of the rapid charge network investigate the reliability record of the charging hardware under consideration.

Connectivity

We recommend that the charge units should be capable of communication with a back office system through the Open Charge Point Protocol (OCPP)[26]. The OCPP allows chargepoints and central control systems from different vendors to easily communicate with each other, rendering the network operator less vulnerable to individual suppliers. If for example, a manufacturer of hardware ceased trading, it would be straightforward to switch to a different supplier. It will also ensure that if different operators are licensed, the entire network could work as an entity and should an operator acquire another's licence, there will be no compatibility or customer access problems.

OCPP should also make it easier to integrate new technologies (e.g. higher charge rates, inductive charging) in the future and any software designed to provide additional functionality would be compatible across the network. This would help ensure that the network is as future proof as possible and will benefit from advances in functionality in pricing, smart charging and chargepoint problem diagnosis and repair. It is recommended that the latest version of the OCPP is mandated for the taxi network. This would enable compatibility with smart charging should a power constraint become apparent and allow time of day pricing to be implemented if deemed necessary.

Back office software

Back office software requirements to provide the functionality needed to reliably maintain and operate the network includes:

- Detailed information on chargepoint activity including real-time status (available, no vehicle plugged-in, vehicle plugged in and charging, vehicle plugged in and charged, fault with the unit)

[26] Details of the OCPP are available from the Open Charge Alliance www.openchargealliance.org

- Charging start and finish times
- Electricity consumption by chargepoint per hour/day
- Energy provided to each vehicle by charge event
- Management of power demand to avoid network overload
- Remote software updates and maintenance
- Support for customer service and chargepoint maintenance staff
- Provision of a live map to show available chargepoints compatible with the vehicle the driver is in and allowing the driver to book the most appropriate unit.

A comprehensive management system will allow reporting to stakeholders by the network operator(s) who may include taxi drivers' representatives, public and private funders, the DNO, TfL and customers. It will also enable identification of the most popular chargepoint locations and peak periods of use. The data provided would be used to ensure that the development of the network, both in terms of the number of chargepoints, and their distribution, meets future demand.

Payment methods

Pay as you go (PAYG) was the method preferred by 58% of the taxi drivers surveyed. The options are:

- SMS (as for car parking).
- RFID card.
- Smartphone app.
- Contactless and chip and pin card payment.

The cost to use each of these systems should be taken into consideration to minimise any unexpected charges for the users of the network.

Service Level Agreements (SLA)

Reliability and uptime (the time that an individual chargepoint will be fully functional) will be paramount to the success not only of the charging network but of the taxis using it too. The network operator(s) will be responsible for reliability and it is suggested that uptime at a relatively high rate (say 90 per cent) should be set as a KPI for the operator(s).
There are many options when it comes to maintaining the network, all with different cost implications, it should be borne in mind however that the cheapest solution may not deliver the required service. It is not within the scope of this study to estimate the cost of providing a service and maintenance package for a charging network for London taxis.

The network operator(s) would need to determine KPIs for reactive and routine maintenance and repair.

A high level of service will be required from the outset if drivers are to be persuaded that the technology works and it is worth investing in the vehicles. A high percentage uptime requirement will ensure that the network operator(s) installs chargepoints and back office systems which will offer the reliability required.

Business Model

There are a number of constraints which an operator will face if the chargepoint network for taxis is to be funded solely on a commercial basis. Therefore, it is recommended that financial support for providing rapid charge infrastructure, and additional works such as substation upgrades, needs to be a priority for future spending.

Constraints include:

- A new substation will be required at many of the sites, both for rest ranks and at Central London charging hubs. The costs for this could be in the order of £100,000 to £200,000, according to UKPN though exact costs require surveys to be carried out and quotations obtained. If this investment is not made at the outset, it is very likely that as plug-in taxi numbers increase it will not be possible to provide an adequate number of chargepoints, or power to individual chargepoints will need to be reduced when demand is at its greatest, or both.
- Cost of land to site a substation, which has a $4m^2$ footprint. This could be several times the cost of the substation.
- Cost of installation of the chargepoints and associated ground works at an early stage in the electrification of the taxi fleet. The returns from payment for charging may be low in the early years until the number of chargepoints and turnover has increased.
- Constraints on the amount a network operator(s) can expect drivers to pay for a recharge. E-REV taxi drivers will operate vehicles in ICE mode if the cost to charge during a shift is too high as the following scenarios demonstrate.

Pence per mile costs driving an E-REV taxi

We have assumed that a 50kW chargepoint will deliver, on average, 10kW of power to a taxi during a 15 minute charge. The following table shows how the cost of this charge will be constrained by the fuel economy of the vehicle when it is driven in ICE mode. The table shows the pence per mile in EV mode based on six potential tariffs. The cost of running the same hypothetical vehicle on petrol at a fuel cost of £1.20 per litre is considered for four fuel consumption scenarios.

Fuel consumption (petrol)	Cost of a 15 minute charge delivering 10kW					
	£2.50	**£3.00**	**£3.50**	**£4.00**	**£5.00**	**£6.00**
40 MPG	14 ppm	14 ppm	14 ppm	14 ppm	14 ppm	14 ppm
35 MPG	16 ppm	16 ppm	16 ppm	16 ppm	**16 ppm**	16 ppm
30 MPG	18 ppm	18 ppm	18 ppm	18 ppm	18 ppm	18 ppm
23 MPG	24 ppm	24 ppm	24 ppm	24 ppm	24 ppm	24 ppm
PPM in EV drive mode	8 ppm	10 ppm	12 ppm	14 ppm	17 ppm	20 ppm

Pence per mile comparison

Pricing at or above £5 per charge would offer the driver no cost advantage if the vehicle were achieving 35 mpg. At current fuel prices a charging cost of £3.50 is likely to be the maximum possible, or it would not be worthwhile for E-REV drivers to use the charging infrastructure and will make running a pure-EV an expensive choice.

This will constrain the income for the network operator which would impact on the return on investment for the installation and for the operation of the chargepoints.

Return on investment – infrastructure

We have already seen that it will be necessary for the electricity network to be reinforced and there are substantial costs associated with this. Additionally, each rapid chargepoint installation will be unique; different sites will require different levels of investment at each stage of their development until they become operational.

It is possible therefore, to use only indicative costs in any examples and it will be necessary for a network operator to model the costs and potential return of any proposed installation to accurately determine its viability.

The following examples demonstrate:

- How the constraint on the cost of a 15 minute charging event impacts the return on investment of the installation.
- The impact of a 75% grant, in line with recent OLEV rapid chargepoint grants.
- The impact of a network operator funding reinforcement of the electricity network.

A charging hub with three chargepoints (which are 50kW DC CHAdeMO and CCS compatible) is considered in each case. The scenarios compare the potential income at two levels of chargepoint utilisation and two costs for each 15 minute recharging event as follows:

- High utilisation – 20 charge events per day
- Low utilisation – 10 charge events per day
- High cost - £3.50 per charge event
- Low cost - £2.00 per charge event

It is assumed that:

- 12.5kW will deliver 10kW of power to the vehicle
- Network operator pays £0.09 per kWh for electricity
- No cost for land use or purchase is included, or electricity charges on top of the unit rate such as a fixed daily charge.
- The cost of the chargepoint hub is amortised over five years.
- An annual interest rate of 5% has been used to account for funding costs.
- The chargepoints are estimated to cost £25,000 each to purchase and a further £25,000 per hub (i.e. three chargepoints) for installation
- An annual SLA of £2,000 per chargepoint is included for maintenance

The hardware, installation and SLA costs are based on price guidance provided by chargepoint suppliers and installers during our discussions and may not reflect the cost of any individual installation.

The first example assumes no cost to the network operator for substation upgrades or installation of a new substation and no grant for the purchase and installation of the chargepoints.

No Infrastructure Grants	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	High use (20 charges /day)		Low use (10 charges /day)	
	High cost	Low cost	High cost	Low cost
Price for 15 minute charge	£3.50	£2.00	£3.50	£2.00
Forecast income	£265,650	£151,800	£132,825	£75,900
Cost including SLA & interest	(£155,000)	(£155,000)	(£155,000)	(£155,000)
Cost of Electricity	(£22,770)	(£22,770)	(£11,385)	(£11,385)
5 year income (loss)	£87,880	(£25,970)	(£33,560)	(£90,485)

Network operator business model 1

In this example there is only a business case if the price of the charging events is at the upper end of what is considered possible based on our assumed vehicle running cost, and if a high level of utilisation of the infrastructure is assumed.

The second example considers a 75% grant towards the infrastructure and installation:

75% Infrastructure Grant	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	High use (20 charges /day)		Low use (10 charges /day)	
	High cost	Low cost	High cost	Low cost
Price for 15 minute charge	£3.50	£2.00	£3.50	£2.00
Forecast income	£265,650	£151,800	£132,825	£75,900
Cost including SLA & interest, net of grant	(61,250)	(61,250)	(61,250)	(61,250)
Cost of Electricity	(£22,770)	(£22,770)	(£11,385)	(£11,385)
5 year income (loss)	£181,640	£67,780	£60,190	£3,265

Network operator business model 2

Providing a 75% grant towards the cost of the infrastructure would likely allow network operators to create a business case for installing chargepoints.

Installing more than two chargepoints or future-proofing a site for more chargepoints to be added in the future may well require a new substation, according to UKPN. They estimate that this could cost anywhere from £100,000 to £200,000. Therefore in the third example, below, we consider the impact of the network operator paying for a new substation at a cost of £150,000.

75% Infrastructure Grant Operator pays for substation	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	High use (20 charges /day)		Low use (10 charges /day)	
	High cost	Low cost	High cost	Low cost
Price for 15 minute charge	£3.50	£2.00	£3.50	£2.00
Forecast income	£265,650	£151,800	£132,825	£75,900
Cost including SLA, & interest, net of grant	(61,250)	(61,250)	(61,250)	(61,250)
Cost of Electricity	(£22,770)	(£22,770)	(£11,385)	(£11,385)
Cost of substation	(£150,000)	(£150,000)	(£150,000)	(£150,000)
5 year income (loss)	£31,650	(£82,220)	(£89,810)	(£146,735)

Network operator business model 3

This example indicates significant losses, except in a high-use, high-cost scenario.

In summary, TfL and prospective network operator(s) should bear the following in mind:

- In a purely commercial model the cost of the substation cannot be borne by the network operator(s) except in the instance where a high price and high utilisation is assumed. Even here, a potential annual income of £6,000 is not a sustainable return on the substantial investment required.
- The scenarios where a business case is evident assume 20 charging events per day. It is highly unlikely that this will be achieved in 2018 when numbers of plug-in taxis on the road will be relatively low.
- None of these models include the cost of land to site the chargepoints or substation if required.
- If more chargepoints are installed, economies of scale will be realised and there may appear to be a business case for the network operator to fund capacity upgrades. However, levels of utilisation will be very low for the first few years therefore the significant capital outlay required would be a barrier to investors.

Investment

The examples above suggest that it will be difficult to achieve a purely commercial model for a reliable rapid charge network for London in the short-term. The returns for investors are compromised by the high cost of upgrades to the electricity supply without support from local or central government. Once the rapid charge network is established and in operation, the data received will inform its future development. This will include more chargepoints and as required, further capacity increases perhaps through electricity storage.

Following discussions with infrastructure operators and installers there may be commercial operators who might invest some capital alongside public funding. For example, the model OLEV have successfully used elsewhere, where infrastructure is 75% grant-funded with the remainder covered by the private sector could potentially be explored in a further piece of research. Funding of £20 million for charging infrastructure and taxi top up grants has been announced by OLEV[27], in a competition for local authorities who commit to supporting a step change in cleaning up the taxi fleets in their areas through the introduction of ULEV taxis. London will be bidding for a share of this fund. London has also been allocated £10 million in the National Infrastructure Plan for charging infrastructure[28]. This is in addition to London's £65 million fund for accelerating London taxi drivers' transition to zero emission capable taxis.

Regulation

There are three key points around network regulation:

1. A network operator could be a network installer, an existing network operator, a vehicle or chargepoint manufacturer, an Independent Connection Provider (ICP), or a consortium including some of these stakeholders and taxi drivers' representatives.
2. Reliability of the network is of paramount importance.
3. We recommend that a regularity authority should ensure that the network operator(s) invest appropriately and operate the network efficiently

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[27] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/426908/_20-million-ulev-taxi-scheme-guidance-for-participants.pdf

[28] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381884/2902895_NationalInfrastructurePlan2014_acc.pdf

05 Installation and operation of chargepoints

Introduction

We estimate that approximately 45 rapid chargepoints should be in place by January 2018, and approximately 90 by the end of that year, to support the introduction of rapid charge capable plug-in taxis. Correctly locating rapid chargepoints for taxis is vital to facilitate the shift from conventional to plug-in vehicle technology. It should enable those using the infrastructure to do so with minimal impact on their daily routine and allow them to benefit from the lower operating costs while not being compromised in terms of business turnover. Most importantly, it will help reduce the impact of these vehicles on London's air quality.

However, installing chargepoints in London is challenging. Land availability, constraints on the supply of electricity and planning guidelines all restrict the potential sites that could be used. Additionally, organisations should consider factors including the type of chargepoint to use the level of Service Level Agreement (SLA) to provide and how to run the network on a day to day basis. The purpose of this section is not to provide definitive instructions on how to install and setup a network. Instead, the guidance and suggestions we provide are intended to help London Boroughs and other stakeholders understand the various factors to be considered. Additionally, this guide signposts other resources that can provide assistance.

Choosing the right equipment

Taxi drivers need to be able to recharge their vehicles quickly, ideally without being off the road for longer than they would in a conventionally fuelled taxi. Therefore the majority of the chargepoints for taxis should offer the fastest rate of charge available. In our opinion, 50kW DC chargepoints currently offer the best solution to meet taxi drivers' requirements. Compatibility with both CHAdeMO and the Combined Charging System is recommended.

Chargepoints must be reliable and there are concerns in the industry that some units currently in service have a poor record in this regard. It is important therefore to investigate the reliability record of the hardware under consideration.

The charge units should be capable of communication with a back office system through the Open Charge Point Protocol (OCPP).

Back office software should provide the functionality needed to reliably maintain and operate the network including:

- Detailed information on chargepoint activity including real-time status
- Charging start and finish times
- Electricity consumption by chargepoint per hour/day and energy provided to each vehicle by charge event
- Management of power demand to avoid network overload

- Remote software updates and maintenance
- Support for customer service and chargepoint maintenance staff
- Provision of a live map to show available chargepoints and facilitate booking

A comprehensive management system will allow reporting to stakeholders to ensure that the development of the network, both in terms of the number of chargepoints and their distribution meets future demand.

Business planning

While the cost of installing one chargepoint could be around £18,000 (excluding the cost of the hardware itself) this usually does not double when two chargepoint are installed. Therefore installation costs have an economy of scale when more chargepoints are installed at a location.

Conversely, larger chargepoint installations are more likely to require expensive upgrades to the electricity supply. Without support from the public sector, chargepoint operators may struggle to create a business case if the cost of a new substation is included. Section four has more details concerning business models.

Site selection and planning

We have mapped where we recommend the initial chargepoint infrastructure should be located. In most cases this is in central London locations such as rest ranks or cabmen's shelters. However we also note a requirement for additional chargepoints primarily on the periphery of Central London. These will enable drivers commuting in from the suburbs or further afield to top up their batteries before their shift, or to do so when returning from a longer fare. It is assumed that these hubs will be based on private or public land, for example unused TfL property unsuitable for housing development. There may also be a requirement for additional on-street infrastructure as the number of vehicles increases.

The following steps to select a suitable site and prepare for installation are presented in the order we recommend they are taken:

1. Determine approximately where to locate infrastructure based on market research to assess likely demand. Chargepoint networks developed without due consideration to demand can suffer from low utilisation rates as a result.

2. Once the general area has been identified, land availability is the main factor in choosing the specific site. For installations requiring a new substation, ensure there is space for a substation with a c.4m^2 footprint.

3. Apply to the relevant DNO for an initial budget estimate, providing details of the location and the required power. The total maximum capacity of all the chargepoints will be used to determine the total load. The DNO will provide an approximate idea of costs for connection and any necessary upgrades. Any capacity identified is not reserved at this stage.

4. Carry out a site audit, taking into account the following considerations:
   - The layout and location of charging bays, including whether double lines or underutilised existing parking bays are appropriate.
   - The location of the existing or proposed substation in relation to the position of parking bays which may need to be rearranged to reduce cable runs and ground works.
   - Land ownership in the vicinity may impact on routing of electricity connections.
   - Location of other utilities such as gas, sewers and telephone. Service covers may indicate underground congestion, increasing complexity of connection.
   - Bays should be away from areas of high density footfall. Consider other safety issues pertaining to pedestrians.
   - Ensure that infrastructure will not negatively impact surroundings, such as historic buildings
   - Quality of lighting to ensure safe operation of infrastructure
   - CCTV coverage to ensure security of infrastructure
   - Availability of GPRS (2G) mobile phone signal or specified alternative
   - For an on-street site audit, consider how parking for re-charging will fit in with existing restrictions and where signage for parking bays will be installed (e.g. on street furniture or walls).
   - For a site audit on private property, ensure that vehicular access to and from the site is adequate, taking into account any increased traffic flow generated by short duration recharges. Ensure access is possible for a lorry mounted crane (HIAB) which is required for the installation of a substation. Access must be maintained after any development of the site in case the DNO has reason to remove or replace the substation in the future.

5. The size of rapid chargepoints means that planning permission is likely to be required, as it is unlikely that they would come under the Permitted Development rights for electric vehicle charging infrastructure. However smaller rapid chargepoints under 1.6m high are becoming available which may meet Permitted Development requirements. Borough planning officers should therefore be consulted regarding planning permission for rapid chargepoint sites.

6. The design and appearance of the chargepoints should be carefully considered and discussed with the borough and TfL to ensure that any design is acceptable and suitable for the location. Guidance documents published by Department for Transport and TfL consider the impact of street furniture on traffic management and streetscapes, and links to these are provided at the end of this chapter.

7. Request a formal quotation from the DNO to determine exact costs, providing the power on date, substation location and meter positions. This can take up to 90 days but typically as little as three weeks. At this point the DNO will reserve capacity for 90 days before it is

released. This can be done in parallel with step five. A contingency will be necessary to cover any unforeseen additional costs incurred by the DNO.

8. If the chargepoint will be located on-street, a Traffic Management Order (TMO) will be required to allow enforcement of the bay. Draft TMOs involve a consultation period, usually 21 days, so this can be carried out while waiting for the DNO to provide the quotation.

9. Engage an electricity supplier. This can be done in parallel with step seven.

Installation

The DNO must carry out all non-contestable work, including determining the point of connection to the distribution system, carrying out work to reinforce the distribution system, agreeing and obtaining any legal consent that may be required and connection to the distribution system and energisation. Contestable work (the rest of the installation process) can be carried out by an Independent Connection Provider (ICP) or the DNO.

Further considerations when completing the installation include:

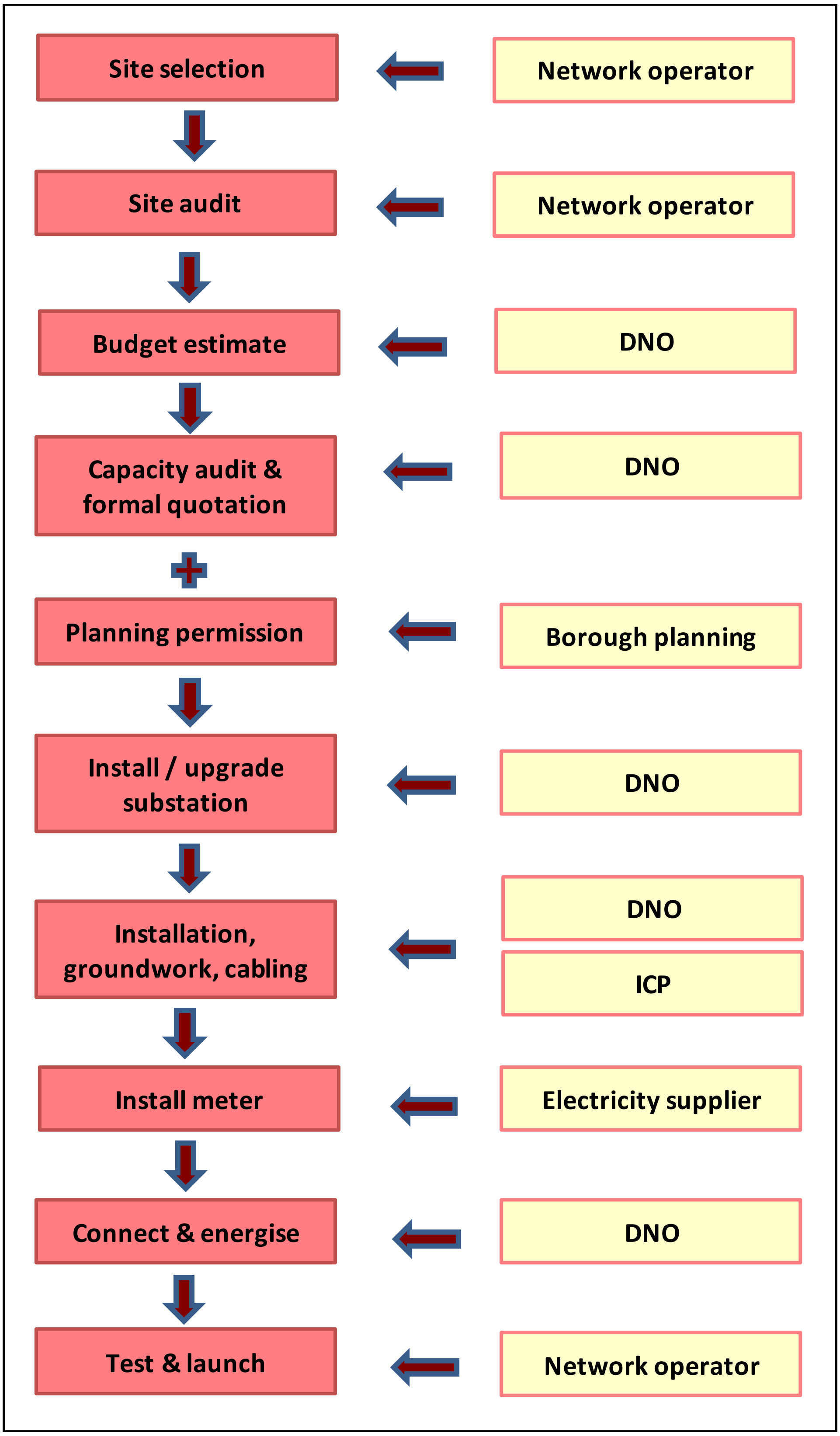
- Controls and outlets should be between 0.75 and 1.2m above the ground so that they are accessible to everyone, including disabled users, in line with British Standard on the design of buildings BS 8300:2009 + A1:2010.
- Charging points should be installed such that access covers can be removed for maintenance and to allow adequate space for ventilation.
- Trip hazards should be avoided and provision made for the safe storage of tethered cables when not in use.
- Impact protection should be installed, e.g. steel bollards to prevent vehicles being driven into the infrastructure.

Operating the network

Pay-as-you-go (PAYG) is preferred by the drivers we surveyed. Section four has further details. The importance of reliability and uptime (we recommend this should be above 90% based on conversations with industry experts) should be considered when devising Service Level Agreements (SLAs). Ideally the SLA will include 24/7 remote reaction time within 10 minutes and a site visit within two hours with issues resolved within 24 hours in order to guarantee high uptime. Subcontracting to an organisation with service personnel already on the ground may help reduce costs and provide a high level of customer service.

The tariff for access to the rapid charge network must provide E-REV drivers with an incentive to use electric-only power in order to increase utilisation rates. At current fuel prices a tariff of £3.50 per 15 minutes or c. 30p/kWh is likely to be the maximum possible to encourage utilisation.

Summary and further information



Provisional installation process

Planning and borough perspective

It should be noted that The Town and Country Planning (General Permitted Development) Order 1995 was amended and came into force on 1st October 2011 to allow Permitted Development rights for electric vehicle charging infrastructure as follows:

Two new classes are added to Schedule 2, Part 2 (minor operations) to grant permitted development rights for:

- *wall mounted electrical outlets for recharging electric vehicles within off-street parking areas (Class D); and*
- *upstands for recharging electric vehicles within off street parking areas (Class E).*

Schedule 2, Part 12 (development by local authorities) is amended to clarify that local authorities can install on-street charging points as permitted development.

However, the size of most current rapid chargepoints mean that it is unlikely that they would come under the permitted development rules and therefore the usual planning process will apply. However smaller chargepoints under 1.6m high are becoming available which may meet the Permitted Development requirements. Borough planning officers should therefore be consulted regarding planning permission for rapid chargepoint sites.

Guidance documents published by Department for Transport and TfL consider the impact of street furniture on traffic management and streetscapes. Example guidance includes:

- Consider how well the design of the infrastructure will fit in with its surroundings
- Where possible, fix signs to existing street furniture or mount on walls
- Ensure consistency of colour with other street furniture
- Consult with the borough and TfL to ensure designs are in accordance with streetscape guidance

Installers of infrastructure consider that the planning process is straightforward subject to streetscape guidance being followed.

Traffic management order

Where the infrastructure is on-street and access will be enforced under Highway Regulations it is necessary to create a Traffic Management Order (TMO). A TMO provides the means by which consultation is carried out with statutory consultees as well as the general public. It provides details of the parking restrictions, kerbside location of the bay and other information relevant to enforcement.

For on-street charging bays, once the location and layout have been determined the borough must draft and publish a TMO. The procedure is the same as that undertaken to introduce a normal parking bay. Draft TMOs are sent to consultees and are also advertised locally.

Boroughs stipulate the period within which objections or representations can be made against the published proposals, which is usually 21 days.

Safety

The site audit sections above cover safety from a trip hazard and vehicle movement perspective. It is recommended that safety standards such as those required by OLEV (detailed in section two) for rapid chargepoint grants are made a requirement for all equipment and installations.

Contestable & non-contestable work

The network operator should familiarise themselves with the areas of work relating to utility connections that may be carried out as contestable or non-contestable work. Contestable work can be carried out by an Independent Connection Provider (ICP) or the relevant DNO. Non-contestable work comprises elements of the project that can only be carried out by the DNO, including:

- Processing the application for a connection
- Determining the point of connection to the distribution system
- Carrying out work to reinforce the distribution system
- Agreeing and obtaining any legal consent that may be required
- Connection to the distribution system and energisation.

The following process should be followed:

- A completed application form for an electricity connection (projects) is required. This covers developments with a power requirement of more than 70kVA.
- The DNO will work with the network operator on the design of the installation
- Payment for the installation will be required
- The DNO's delivery team will manage and deliver the project in its entirety or, where an ICP is engaged, the non–contestable element of the installation.

Metering for the installation will be provided by the appointed electricity supplier.

Resources

- Details of the OCPP from the Open Charge Alliance www.openchargealliance.org
- UK Power Networks www.ukpowernetworks.co.uk
- Scottish and Southern Energy www.ssepd.co.uk
- Information about Permitted Development Rights from the Department for Communities and Local Government Planning Portal www.planningportal.gov.uk
- Transport for London streetscape guidance www.tfl.gov.uk
- Department for Transport streetscape guidance www.gov.uk
- Find the appropriate local authority www.local.direct.gov.uk
- Find an Independent Connection Provider (ICP) from the Lloyds Register website www.lloydsregister.co.uk

- ENEVATE (European Network of Electric Vehicles and Transferring Expertise) has published an *Electric vehicle charging infrastructure toolkit* http://www.enevate.eu/ib/site/documents/media/46941192-4f72-0616-2d2e-1aea8b30068a.pdf/WP2_Draft_
- UK EVSE www.ukevse.org.uk

06 Grid capacity

Introduction

As the previous section illustrated, selecting locations and installing rapid chargepoints is complex. One of the major potential issues is the constrained supply of electricity from the grid. A site survey will be required at each location to determine whether sufficient capacity exists in the network. For a small installation, such as a single chargepoint, it is less likely that upgrades to the grid supply will be required. However, where an operator wishes to install several rapid chargepoints, investment such as transformer or substation upgrades or even a new substation may be needed.

Additionally, the process is not as straightforward as simply asking the DNO to provide guidance on where grid capacity is available. Due to fluctuations in electricity supply and demand, DNOs such as UKPN do not hold this information. Neither do factors such as proximity of your chosen site to a substation determine available capacity. Each site requires an individual site survey, at which point the DNO will determine if capacity exists and quote for any necessary grid upgrades.

Network reinforcement

Installing multiple chargepoints at a given site will add significant demand to the already constrained grid. Therefore, network reinforcement may be required to provide sufficient power. Required upgrades may include:

- An HV/LV connection (reducing the voltage from the high voltage supply) if there is no low voltage in the vicinity of the chosen site.
- An upgrade to the substation to increase available capacity.
- A new substation may be required, with costs in the order of £100,000 to £200,000. This does not include the cost of land which could be several times the cost of the substation.

Given the estimated number of rapid chargepoints required to support zero emission capable taxis, we believe that the cost of upgrading the electricity network is likely to be the greatest potential barrier to developing rapid charge infrastructure. However, it is likely to be a worthwhile investment, partly because the upgraded supply may be useful when inductive charging is introduced by manufacturers in the future.

According to Ofgem's guide to electricity distribution connections policy document[29], the connecting customer (in this case the chargepoint network) must pay a proportion of the cost of network reinforcement where it is required. The proportion is calculated based on the share of new capacity created that will be used by the connecting customer. The remainder of the cost

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[29] https://www.ofgem.gov.uk/ofgem-publications/87259/guideelectricitydistributionconnectionspolicy.pdf

will be paid by other network users through their electricity bill. However, it is impossible for us to say at this stage what proportion of the cost of network reinforcement would be attributed to the chargepoint operator for any given installation.

In addition to reactive network reinforcement, Distribution Network Operators can invest ahead of need and recover the cost from its customers through their electricity bills. However, they can only do so when they have demonstrated that the benefits to customers outweigh the cost and will benefit network users. Unless it can be demonstrated that installing rapid chargepoints (with necessary network reinforcement) is of benefit to other network users, it may be that the chargepoint operator will be liable for the full cost of upgrades.

Ofgem regulates how much money DNOs can budget for load related capital expenditure (investment in reinforcing the network to cater for growth in electricity demand) via a mechanism called DPCR5 (Distribution Price Control Review 5). DNOs cannot make speculative upgrades of the network unless they have demonstrated that such upgrades will benefit network users. If over a thousand plug-in taxis are going to be added to the London vehicle parc every year, the relevant DNOs and Ofgem should consider necessary investment in the network to cope with this extra demand.

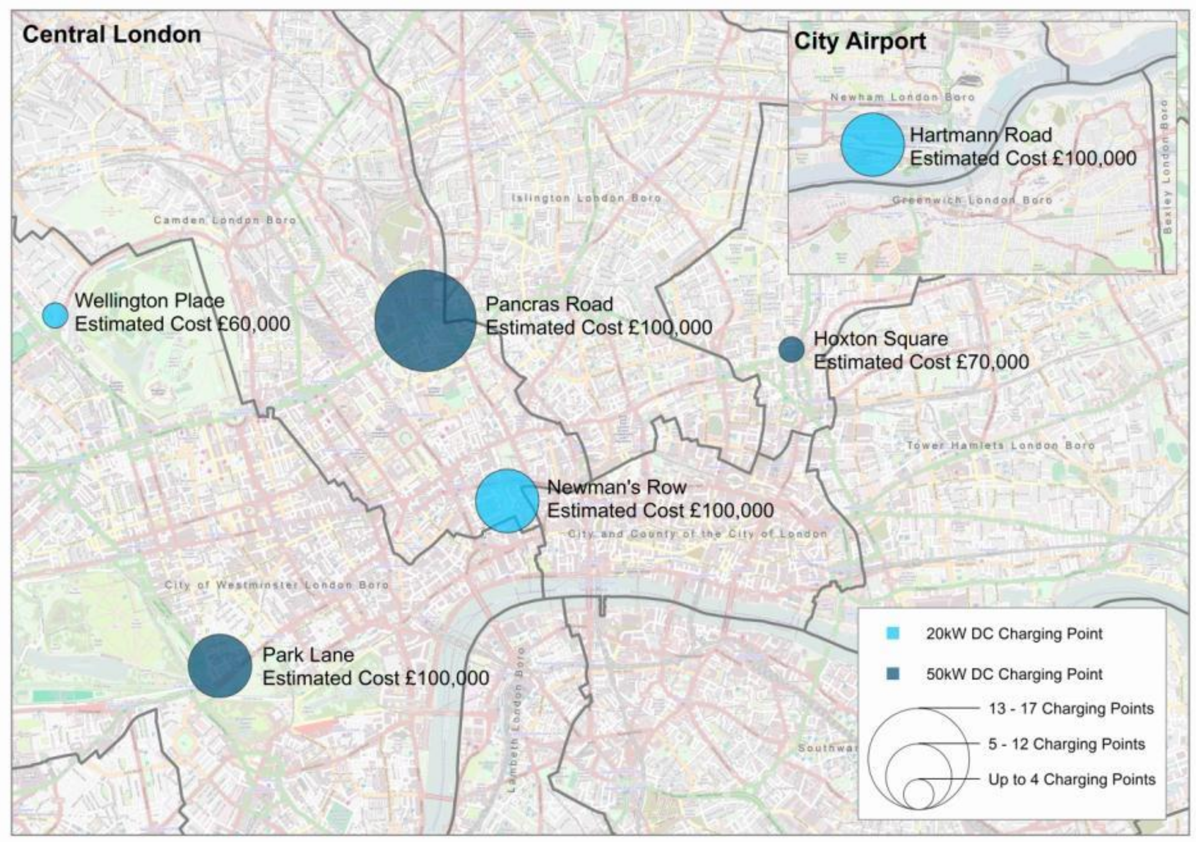
Grid upgrades at potential chargepoint locations

To help illustrate the above points, we asked UKPN to estimate prices for connecting infrastructure at six sites (five in central London and one at City Airport). The locations selected and the hypothetical chargepoint details are detailed in the table below.

Category	Location	Power rating	Number of chargepoints
Station	Pancras Road (near Great Northern hotel)	50kW DC	17
Hotel	Park Lane	50kW DC	12
Airport	Hartmann Road / London City Airport	20kW DC	8
Cabmen's Shelter	Wellington Place	20kW DC	4
Taxi rest rank	Newman's Row / Lincoln Inn Fields rank	20kW DC	10
Other	Hoxton Square	50kW DC	4

Hypothetical chargepoint locations for UKPN site survey

The estimates from UKPN for the provision of necessary grid upgrades at each of these locations are illustrated on the following map:



UKPN estimated costs

Location	Budget estimate	Notes
Pancras Road (near Great Northern hotel)	£100,000	Dedicated substation
Hilton Park Lane	£100,000	Dedicated substation
Hartmann Road / London City Airport	£100,000	New HV / LV connection
Wellington Place	£60,000	Substation upgrade
Newman’s Row / Lincoln Inn Fields rank	£100,000	Dedicated substation
Hoxton Square	£70,000	Substation upgrade

UKPN estimated upgrade costs

There is no direct correlation between the required power and the cost of making the necessary upgrades.

- At Wellington Place, for example, UKPN estimated £60,000 is required to add four 20kW DC chargepoints to the grid.
- Conversely at Hoxton Square, £70,000 is needed to add four 50kW DC chargepoints to the grid.

Investigating potential electricity supply constraints early in the process of assessing locations should allow the selection of sites with lower upgrade costs.

Potential solutions to manage demand

- Consideration should be given to how the peak times when drivers are likely to charge compare with grid load demand profiles. Further work is required in two areas in order to do this:
    1. Determine when drivers are most and least likely to access charging infrastructure during the day.
    2. Analyse substation load profiles on a site-specific basis once potential chargepoint locations have been determined.

- Consideration of a pricing incentive to influence charging times. For example, using time of day pricing to encourage drivers to access charging at times of lower electricity demand would help to balance the grid.

- Energy storage, either with dedicated batteries or as a second life for used EV batteries which has two potential benefits.
    1. More chargepoints could be installed at a given location without additional network upgrades.
    2. As the proportion of renewables like wind and photovoltaic which are susceptible to fluctuations increases in the National Grid, local energy storage can help to smooth out grid supply and demand.

- Locally generated renewable energy can further decarbonise the supply of electricity to taxis. This technology is already in use in the Netherlands, where Fastned charging stations generate electricity using photovoltaic panels. This option may be suitable for larger charging hubs in London.

- Battery swapping technology could also help to balance grid demand but currently this is not a mainstream technology and would be a land intensive solution.

- Grid balancing through a localised smart grid to manage the power delivered by individual chargepoints is advisable; though this must be balanced against drivers' expectations of the time it will take to recharge their vehicles.

Additionally, to reduce the total cost of network upgrades, chargepoint network operators should consider either having single points which can be added to the existing network, or installing a cluster or hub of chargepoints, upgrading the network as required.

Additional comments

Given the estimated number of rapid chargepoints required to support zero emission capable taxis, we believe that the cost of upgrading the electricity network is likely to be the greatest potential barrier to developing rapid charge infrastructure. Substations can cost up to £200,000 and if upstream work is required to upgrade the high voltage (HV) supply then further charges will be applicable. Even if the chargepoint installer or operator will not require all the power available from a new substation, they may still be responsible for the full upfront cost.

The adoption of zero emission capable taxis will be mandatory from 2018 so clearly it is essential that appropriate recharging infrastructure is in place in advance of this date. When plug-in taxis go on the road, drivers need to be sure that there is somewhere to charge them during a shift. It is critical that TfL, the network operator(s) and the relevant DNOs work closely together from the outset to manage rapid chargepoint installations and any necessary supply upgrades as these organisations all share responsibility to manage the provision of sufficient chargepoints.

07 Considerations for planning a rapid charge network

Identified barriers and potential solutions

The previous sections have identified a number of obstacles to overcome in order to develop rapid chargepoint networks for plug-in taxis. This section draws together the most significant barriers identified, with proposed solutions where possible.

Grid capacity to support rapid charging

- Finding suitable sites to install rapid chargepoints in central London is a major challenge and is likely to involve either a lengthy round of site surveys until one with sufficient capacity is found, or costly upgrades to the electrical supply. The potential cost of upgrades, which can be well over £100,000 per site, is a major potential barrier to the development of a rapid chargepoint network. Potential network operators are likely to require funding support to acquire and install rapid chargepoints. Additionally they are unlikely to be able to fund the full cost of grid upgrades.

- As covered in the previous section, Distribution Network Operators face challenges when taking an anticipatory approach to investment in network reinforcement. Once zero emission capable taxis are mandated, it is estimated that over a thousand such vehicles will be added to the London taxi parc each year. With this in mind, relevant stakeholders including DNOs and Ofgem should consider the level of investment required to meet this demand.

- Plug-in vehicle uptake has been encouraged in the UK to meet policy objectives on climate change and air quality, and to improve the health and wellbeing of people living and working in London. It is likely that plug-in taxi uptake in London will be constrained if chargepoint operators are expected to pay for upgrades to the electricity supply. Improved air quality is a public benefit and thus measures to improve it should be publicly funded where there is no incentive for the private sector to do so. Stakeholders including TfL, the GLA, OLEV, DNOs and Ofgem should consider how to overcome what we believe is the greatest single potential barrier to the development of a rapid charge network in London.

It should be noted that in response to these obstacles TfL has determined to identify and enable sites for the installation of charging infrastructure across the TfL, borough and private estates. Enabling works will include upgrades of power capacity and groundworks to make the sites suitable for chargepoint installations.

Vehicle funding and running costs

The cost of acquiring and operating a plug-in vehicle will be among taxi drivers' greatest concerns when considering this technology.

1. Drivers should be charged an appropriate fee for using a rapid chargepoint. A cost of more than £3.50 per 15 minute charging event would likely act as a barrier to drivers using rapid charging infrastructure. In particular, drivers of petrol-electric E-REVs would have no incentive to use electric power rather than petrol at costs above this threshold. It is crucial that E-REV drivers use rapid charging rather than relying on the petrol engine once the battery is depleted. Ensuring that E-REVs are rapid charge compatible and that the price of a rapid charge is competitive will be essential, but these points by themselves may not be sufficient; TfL must consider the risks associated with these drivers not utilising their vehicles effectively. Equally, chargepoint operators need to be confident they will generate sufficient income to make a return on their investment. Further work is required to calculate whole life costs for both drivers and infrastructure operators, based on accurate vehicle and chargepoint pricing information.

2. Even where a plug-in taxi is likely to save drivers money based on the total cost of ownership (TCO), the higher upfront purchase or lease cost must not become an obstacle to uptake of these vehicles.

When manufacturers have released pricing information for their vehicles, modelling of whole life costs will be required to help drivers understand the benefits of adopting these vehicles.

Facilities at break locations

Taxi drivers indicated that their choice of break locations is constrained by a shortage of places to park legally and a lack of toilets.

- TfL should investigate the provision of facilities including toilets for drivers, particularly where chargepoints are located for plug-in taxis. In particular, when setting up chargepoint hubs, TfL has the opportunity to facilitate the provision of toilets and other services such as a carwash or café, which could be operated by the private sector.
- Local authorities should be expected to enforce "electric taxi only" parking bays where these are designated.

Home charging solutions

We have assumed that early adopters of plug-in taxis will install dedicated home charging points so they start each shift with a fully charged battery. 48% of drivers sampled have a driveway, 6% have a garage and a further 16% have "other off-street parking at home". Therefore the significant majority should be able to have a chargepoint installed and at the time of writing would be able to benefit from OLEV's Electric Vehicle Homecharge Scheme.

The 30% of drivers who may not be able to install a chargepoint at home may be able to buy a rapid charge compatible E-REV and charge solely from the proposed chargepoint network when driving in London, while commuting using petrol power. Alternatively providing on or off street charging for these drivers should be considered as should rapid chargepoints on arterial roads into London. This infrastructure should be available for use by the private hire trade and other commercial operators and research undertaken on behalf of TfL into the siting of rapid chargepoints for these sectors should be taken into account.

Drivers' perceptions of plug-in vehicles

While not necessarily a barrier, drivers' perceptions of and attitudes towards plug-in vehicles are an important area that TfL should consider when taking forward plans for a rapid chargepoint network.

Our research investigated how likely drivers are to consider purchasing a vehicle which is powered by diesel, petrol, pure-electric, diesel-electric hybrid or petrol-electric hybrid drivetrains. The results are displayed in the table below.

	Diesel	Petrol	Pure electric	Diesel-electric hybrid	Petrol-electric hybrid
Very unlikely	10%	35%	36%	15%	24%
Unlikely	6%	18%	19%	5%	10%
Likely	34%	22%	19%	37%	30%
Very likely	45%	15%	12%	33%	25%
Don't know	6%	10%	14%	10%	11%

Attitudes towards different drivetrains

There are several interesting points to highlight:

- While diesel is the most popular choice, 70% and 55% would consider diesel-electric hybrids and petrol-electric hybrids respectively.
- 31% of respondents are likely or very likely to consider a pure-electric vehicle.
- Conversely, 55% are unlikely or very unlikely to consider a pure-electric vehicle.

Drivers were also asked about their perceived barriers to operating a plug-in taxi, with the results shown below:

Perceived barrier	Proportion of sample
Insufficient range (in miles) between charges	83%
Concern about running out of charge	80%
Nowhere to charge during shifts	66%
High lease / purchase cost	64%
Charging would impact on my productive working time	63%
I may have to charge too often during a shift	63%
Nowhere to charge between shifts	63%
The technology is new and unreliable	48%
Needing to know where the chargepoints are	42%
None	2%

Perceived barriers to operating a plug-in vehicle

Provision of reliable rapid charging infrastructure can potentially overcome these objections, with the possible exception of “high lease / purchase cost” and “nowhere to charge between shifts”. However, it should be backed up with support for drivers, including training on how to use chargepoints and how to maximise the range of their plug-in vehicle through in-vehicle training on smarter driving techniques to increase fuel efficiency. The latter should ideally be provided at no cost to the driver when they acquire their first plug-in taxi.

We recommend that TfL works with taxi drivers’ representatives to understand more about these perceived barriers and how they might be overcome.

Information sharing and communication

Most organisations we spoke with while undertaking this study were willing to share information and thoughts on the development of a rapid chargepoint network. Clearly though, organisations including vehicle and infrastructure manufacturers are cautious about commercially sensitive information entering the public domain.

We would urge TfL to ensure that clear lines of communication are opened and maintained between themselves and the major stakeholders, in particular the vehicle manufacturers and the DNOs. For example, vehicle manufacturers need to understand likely vehicle uptake rates in order to help develop a sustainable business model. Similarly the DNOs will need as much time as possible to plan for the increased demand for electricity across the capital.

Additional considerations

- TfL should consider what will happen when a pure-EV runs completely out of charge, particularly if the vehicle is carrying a passenger at the time.
- There are several clauses in the Abstract of Laws which may need revision.
- We suggest that a booking platform is desirable enabling taxi drivers to find and book chargepoints. This should be a live system, showing the available local chargepoints and facilitating the booking of a recharge. The platform should be updated as new infrastructure is added to the network. Chargepoint operators and vehicle manufacturers should work together to determine how such a platform can be integrated with the vehicles' navigation and telematics systems as well as providing a standalone app based solution.
- Taxi fares are set by TfL and we understand that when reviewing taxi fares, increases in fuel costs are one of the factors taken into consideration. For future taxi fare reviews the charging costs should be taken into consideration along with the cost of the new taxis.

08 Recommendations and conclusions

Evidence from our discussions with taxi manufacturers, chargepoint hardware suppliers and other stakeholders suggests that a rapid charge network is both feasible and necessary to support zero emission capable taxis. The taxi drivers' survey results also indicate that, while there are challenges to overcome, installing a chargepoint network to meet drivers' needs is practicable.

Summary of Recommendations

Taxi manufacturers

- Manufacturers whose vehicle design does not currently include either protocol of DC rapid charge capability for their vehicles, or indeed any form of rapid charging, are encouraged to re-consider their decision in the light of this report.
- Plug-in vehicle reliability was one of the most commonly cited concerns of drivers. Vehicle manufacturers and TfL should consider how to address this potential barrier.
- All taxis must meet the specifications detailed in the "Construction and Licencing of Motor Taxis for use in London – Conditions of Fitness" document. Of particular note for zero emission capable taxis, condition 19.1 states: "An adequate heating and ventilation system must be provided for the driver and passengers and means provided for independent control by the driver and the passengers". Passenger heating is therefore only partially under the control of the driver when carrying a fare and manufacturers should consider the impact this might have on energy consumption.
- Supplementary cabin heaters or seat heaters which reduce the impact of heating on energy consumption should be considered.

Chargepoint network for taxis: planning and business model

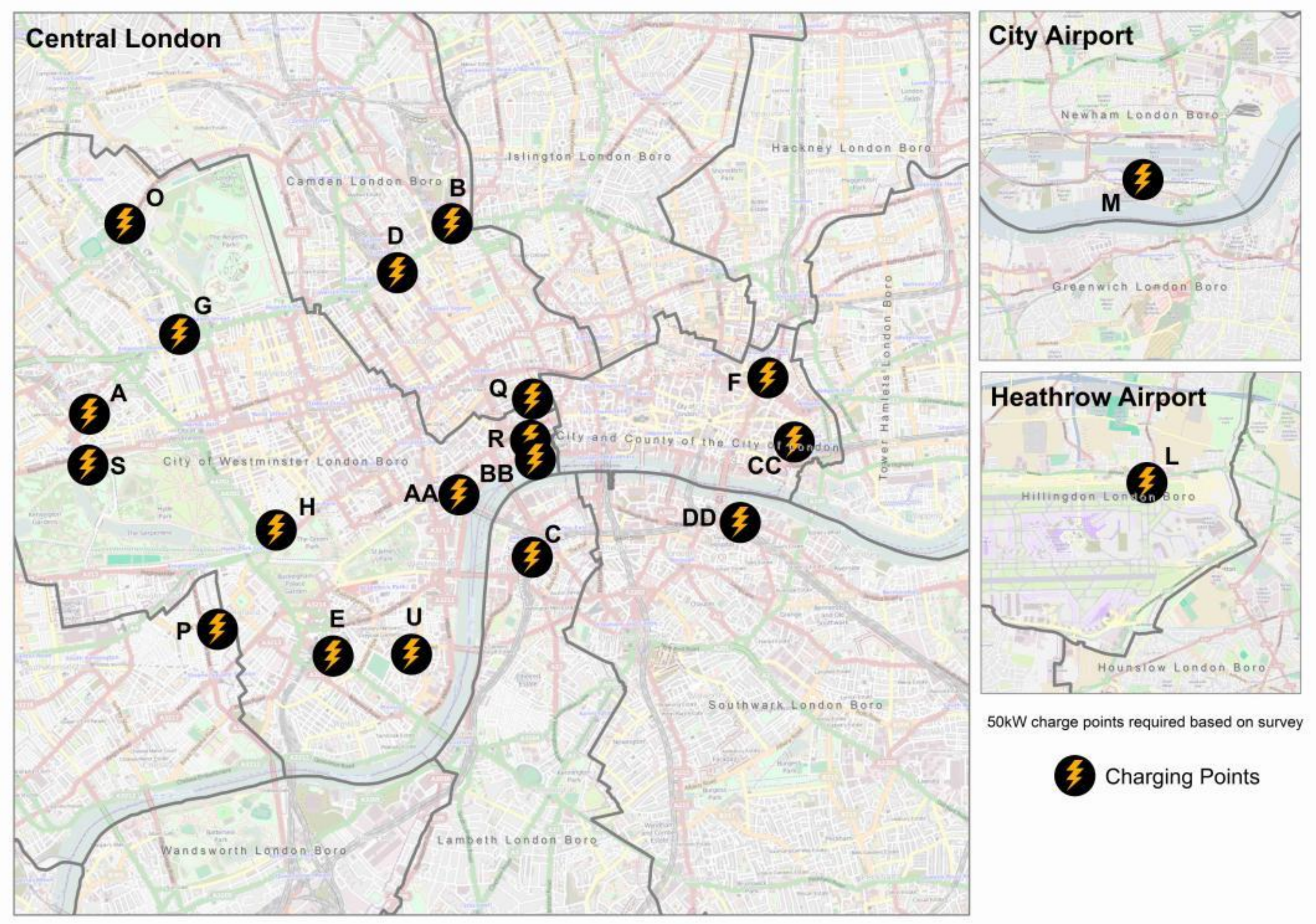
- A dedicated network of rapid chargepoints for the exclusive use of taxi drivers should be created. Recharging infrastructure should be available to support pure-EV drivers, and to allow E-REV drivers to operate on electric-only power as often as possible, in order to reap the benefits of lower running costs and reduced emissions.
- Installers should be mandated to provide rapid (50kW) DC chargepoints compatible with both CHAdeMO and the Combined Charging System.
  - Rapid charging at 50kW will minimise disruption and downtime for drivers. Fast chargers (typically 20 to 25kW), should be the minimum specification in central areas where the size of rapid charge units prevents their installation.
  - DC rapid charging reduces the total cost of the chargepoint network and means vehicles will not need a high output on-board charger.
- Some chargepoint hardware has been reported to have a poor service record. The installer and/or network operator(s) should investigate the reliability record of the charging hardware under consideration.
- Network operator(s) should bear the following points in mind when setting up the network:

    - In 2018, the risk of providing too few chargepoints is likely to outweigh the risk of providing too many. As more plug-in taxis come to market in subsequent years, forecasts for additional installation can be revised downwards if necessary.
    - Equally, there is a risk of low levels of utilisation initially which the network operator(s) must be aware of.
    - Charging infrastructure should be sufficient, strategically located, well maintained, easily accessible to drivers and straightforward to book, use and pay for.
- Our modelling indicates that grants to contribute towards the cost of infrastructure acquisition and installation will be required. Stakeholders including TfL and OLEV are encouraged to consider how this can be made available and managed.
- Installing multiple chargepoints at a given site may require a new or upgraded substation which could cost up to £200,000 per site. If this investment is not made at the outset, it is very likely that as plug-in taxi numbers increase it will not be possible to provide an adequate number of chargepoints, or power to individual chargepoints will need to be reduced when demand is at its greatest, or both.
- The latest version of the Open Charge Point Protocol (OCPP) should be mandated for the taxi network to enable compatibility with smart charging should a power constraint become apparent and allow time of day pricing to be implemented if necessary.

Chargepoint network for taxis: scale and locations

Sufficient chargepoints must be in place by 2018 so that drivers feel comfortable choosing a zero emission capable taxi, and are able to use it effectively. We forecast that by the end of 2018 approximately 90 50kW DC chargepoints will be required and that installing approximately half of these (45) by 1 January 2018 would likely be sufficient to give drivers confidence in the development of the network. These figures should be treated with caution and readers are urged to refer to section three to fully understand how this figure was estimated.

Chargepoints should be located where drivers most frequently use ranks and take breaks, as well as at key transport hubs (stations, airports). Based on analysis of the taxi drivers' survey data which showed the areas where they work and their frequented ranks and break locations, the following chargepoint locations are suggested:



Illustrative chargepoint locations (part 1)

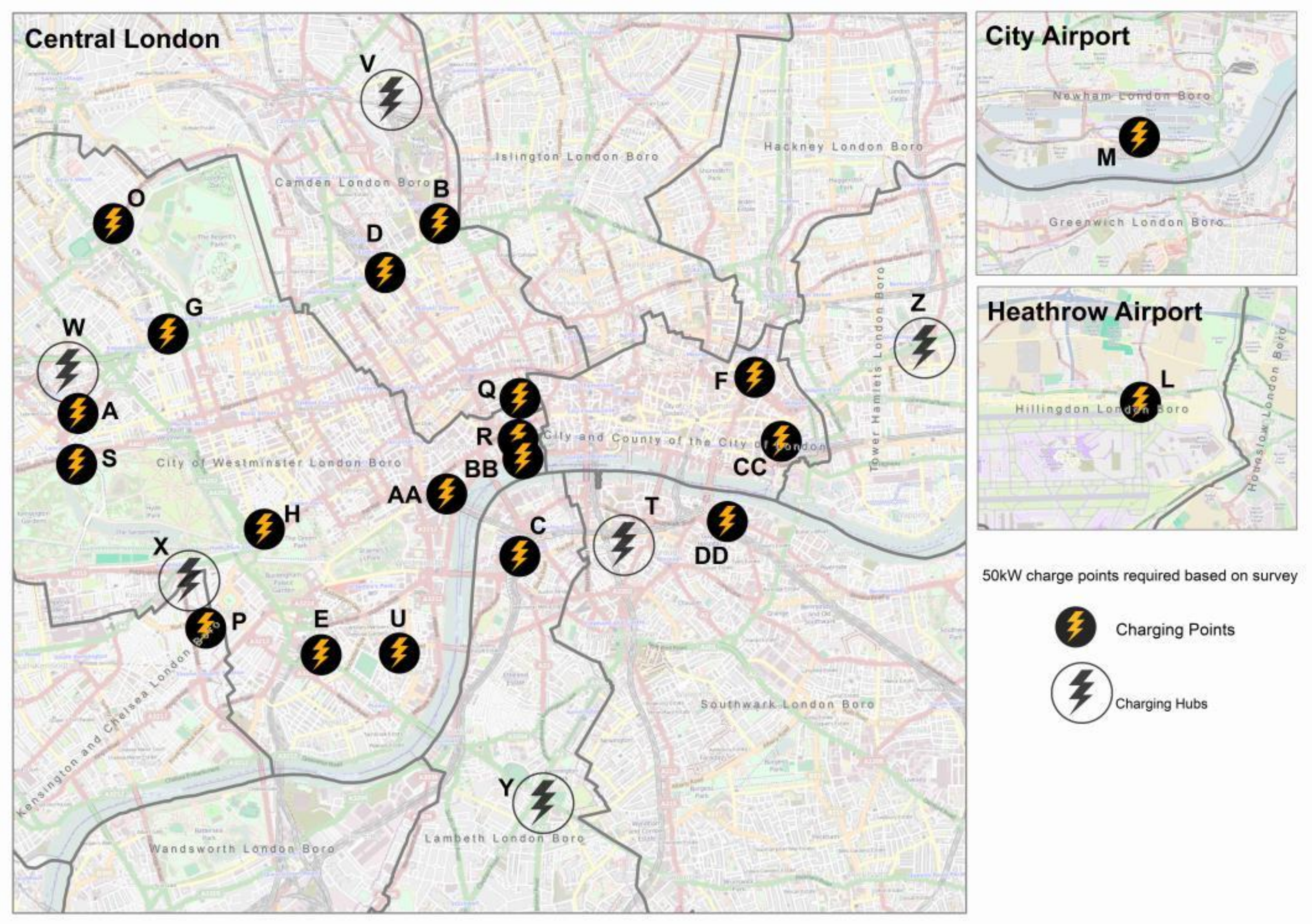
- Stations:
  - Paddington (A), King's Cross / St. Pancras (B), Waterloo (C), Euston (D), Victoria (E), Liverpool Street (F), Marylebone(G), Charing Cross (AA), Fenchurch Street (CC) and London Bridge (DD).
- Hotels:
  - In W1 postcode area.
- Airports:
  - Heathrow (L), London City (M).
- Cabmen's shelters[30]:
  - Wellington Place NW8 (O), Pont Street SW1 (P), Temple Place WC2 (BB).
- Rest ranks:
  - Lincoln Inn Fields WC2 (Q), Strand WC2 (R), Lancaster Gate W2 (S).

- Additional break location:
  - Horseferry Road SW1 (U)

[30] Note that the Thurloe Place shelter was excluded as it is in the middle of the road and therefore not suitable for hosting a chargepoint.

In order to provide the forecast number of chargepoints (c.90) in and around central London between one and four chargepoints should be installed at each location. The exact number to be installed at a given site will depend on the results of Distribution Network Operator surveys to establish local grid capacity.

In addition to these sites, chargepoints should be made available to ensure that the network is prepared should central London become a truly zero emission zone in the future. Drivers would need to be certain that they will have sufficient electric power when approaching or driving in a zero emission zone. Illustrative locations for these additional chargepoints are displayed on the map below.



Illustrative chargepoint locations (part 2)

- Additional locations:
    - Great Suffolk Street SE1 (T), Camley Street King's Cross (V), North Wharf Road near Paddington (W), Hyde Park Corner (X), Oval / Kennington (Y), Whitechapel (Z).

These additional six locations have been termed 'chargepoint hubs' because we suggest that as the network grows towards 2020 and beyond, these locations will eventually host more chargepoints than the space-constrained central London sites. Where chargepoints are installed, they should be incorporated with other facilities such as toilets, particularly at larger 'hub' sites.

Chargepoint network for taxis: operation

Plug-in vehicles must cost no more per mile in fuel when charged from a rapid chargepoint than a new, efficient taxi would cost to run on conventional fuel.
A fee of more than £3.50 per 15 minute charging event or 30p / kWh is unlikely to offer E-REV drivers an incentive to use electric rather than petrol power.

- The majority of drivers surveyed expressed a preference for a pay-as-you-go (PAYG) model; a solution also favoured by chargepoint operators and OLEV. This should utilise either an RFID card, SMS, a smartphone application or contactless and chip and pin card payment.
- Service, reliability and uptime are critical. TfL and the network operator(s) will be responsible for ensuring chargepoints are functional and well maintained.
- Further, we recommend that that TfL and the network operator(s) should work together to collate and manage chargepoint utilisation data to plan when and where additional infrastructure is required.
- Back office software requirements are likely to include detailed information on chargepoint activity including real-time status, charging start and finish times, electricity consumption by chargepoint per hour/day, energy provided to each vehicle by charge event, management of power demand to avoid network overload, remote software updates and maintenance, support for customer service and chargepoint maintenance staff and provision of a live map to show available chargepoints.
- Non-financial in-life incentives, such as access to future zero emission areas, should be actively encouraged, in order to increase adoption rates of plug-in taxis and encourage the use of rapid chargepoints by E-REV drivers.

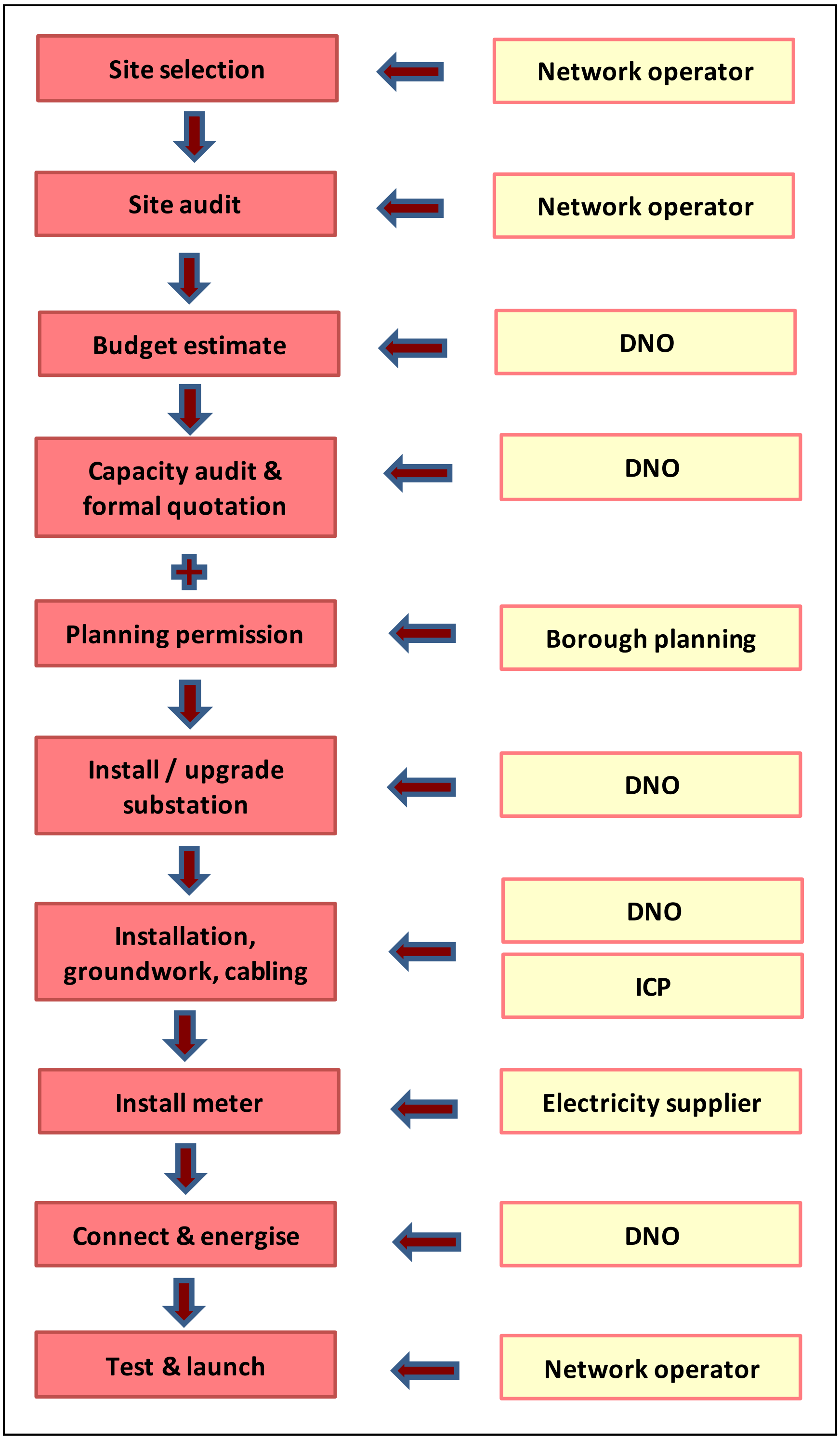
Taxi drivers

- Taxi drivers should be involved throughout the development of a chargepoint network, particularly in identifying locations.
- It is important to build and maintain drivers' confidence in the new technology, as a small number of negative experiences will make implementation of this potentially disruptive technology much more difficult.
- Providing in-vehicle driver training will help drivers use plug-in vehicles efficiently and should be combined with training on the use of rapid chargepoints. Eco-driving training, required for all new taxi drivers before becoming licensed, should be modified and offered to those switching from an ICE to a plug-in taxi.
- Taxi drivers indicated that their choice of break locations is constrained by a shortage of places to park legally and a lack of toilets. TfL should investigate the provision of facilities including toilets for drivers, particularly where chargepoints are located for plug-in taxis.
- A significant minority of taxi drivers will be unable to install a dedicated home charging point and consideration should be given to how alternative solutions can be provided.

- There are concerns and some misconceptions among some drivers about plug-in vehicle technology, particularly around its viability and associated costs. TfL and the vehicle manufacturers should overcome these through communication with drivers, and by providing support as they become accustomed to a new type of taxi.

Chargepoint installation process

The figure below shows the stages in the installation process together with the relevant parties involved:



Provisional installation process

More information about the installation process together with useful resources and contact details can be found in section five of this report.

Timescale for network introduction

Pre-2018

- Install c. 45 rapid (50kW) DC chargepoints by 1 January 2018, using locations provided earlier as a guide. Reforecast numbers once more is known about likely vehicle uptake rates.
- Provide assistance for early adopters to install a dedicated home charging solution.
- Identify sites where grid capacity exists for additional chargepoints and/or carry out upgrades as required.

2018

- Monitor utilisation rates for each chargepoint, and use this information to add chargepoints to existing sites as required.
- Increase number of charge points to approximately 90 by the end of 2018 (refining the number required appropriately, based on utilisation rates and vehicle uptake rates).

2019 onwards

- Expand number and geographical coverage of rapid chargepoints across Greater London based on continued monitoring of utilisation rates.
- Continue to plan ahead to ensure that grid capacity can meet demand.

Electricity network

Given the estimated number of rapid chargepoints required to support zero emission capable taxis, the cost of upgrading the electricity network is likely to be the greatest potential barrier to developing rapid charge infrastructure.

- Upgrading the electricity supply (substations and transformers) to hubs and other chargepoint locations will help to future-proof the network. TfL and network operator(s) should consider how many chargepoints may be required at each site as the number of zero emission capable taxis increases.
- A new substation to facilitate the installation of rapid chargepoints can cost in the region of £100,000 to £200,000.
- There is no direct correlation between the required power and the cost of making the necessary upgrades.
- TfL, network operator(s) and DNOs should work closely together from the outset to manage rapid chargepoint installations and any necessary supply upgrades.
- We recommend that TfL, OLEV, the DNOs, Ofgem and the network operator(s) determine how upgrades at substation level will be funded, given that there is no business case for a chargepoint operator to finance this work.
- Potential solutions to help manage demand on the grid include:
    - Consideration of how the peak times when drivers are likely to charge compared with grid load demand profiles
    - Energy storage
    - Locally generated renewable energy.

Comments on the feasibility of a rapid chargepoint network for taxis

The purpose of this study is to determine the feasibility of a rapid chargepoint network for taxis. Therefore this report does not consider in any detail the viability of other options such as slow, fast or inductive charging. Our research suggests that it is feasible – and necessary – to implement a network of rapid chargepoints to support the introduction of zero emission capable taxis and ensure that the potential financial and environmental benefits are maximised. However, in order to ensure the network is successful, it is critical that the following four areas are addressed.

1. **Zero emission capable vehicles licensed to operate as taxis should be available by 2018. All taxis should be rapid charge capable in order to make a rapid charge network feasible.**

- Several manufacturers have indicated that they are developing zero emission capable vehicles designed to meet the Conditions of Fitness for use as a London taxi. All vehicles described in this report can be driven without producing any tailpipe emissions, although the choice of technology includes both pure electric vehicles and extended range electric vehicles. However, final decisions have not been reached about incorporating rapid charge capability into all the potential taxis. We recommend TfL mandate rapid charge capability for all London taxis and, should they accept this recommendation, to communicate it to the prospective manufacturers as soon as possible.
- When these vehicles are presented for licensing, TfL should work with the manufacturers to establish electrically driven range in 'real-world' conditions and petrol consumption once the battery has been depleted.

2. **Sufficient rapid chargepoints should be installed at strategic locations across London, supported by appropriate KPIs and data management**

- Taxi drivers typically stop for 15 minutes or fewer when they take breaks. Therefore rapid chargepoints are necessary so that drivers can recharge vehicles without additional downtime. 50kW chargepoints (compatible with both major DC protocols) should be installed; they will supply approximately 40 miles of additional range in 15 minutes.
- Where it is not possible to install rapid chargepoints due to constraints on space (for example in central areas), two fast chargepoints providing a minimum output of 20kW should be installed to ensure that sufficient charging capability is installed.
- Chargepoints should be reliable and supported by an appropriate back office system. We recommend that TfL sets KPIs for licensed network operator(s) to ensure they provide sufficient, reliable and well maintained chargepoints. TfL should also collate and monitor chargepoint utilisation data to plan the expansion of the network beyond 2018.

3. Taxi drivers in extended range and plug-in hybrid vehicles should use rapid charging rather than rely on the petrol engine once the battery is depleted

- Even if rapid charge compatible vehicles and rapid chargepoints are provided, there is a significant risk that drivers of extended range and plug-in hybrid vehicles will rely on the petrol engine once the battery is depleted. This will reduce the environmental and financial effectiveness of the new vehicles and will lead to significant under-utilisation of chargepoints. Drivers of rapid charge compatible extended range and plug-in hybrid vehicles should, whenever practicable, use rapid chargepoints once the vehicle battery is depleted rather than switching to petrol power.
- Part of the solution will be to ensure that the cost of rapid charging is less than the cost of petrol, on a pence per mile basis. However, a price incentive to use rapid charging will not be sufficient by itself. TfL should consider the risks associated with drivers not utilising their vehicles effectively and ensure the use of rapid charging becomes normal practice.

4. Electricity supply constraints at the substation level are potentially the biggest barrier to rapid chargepoint provision. Plans for mitigating this should be drawn up.

- Installing rapid chargepoints will add significant demand to the already constrained electricity supply system in London. Given the estimated number of rapid chargepoints required to support zero emission capable taxis, the cost of upgrading the electricity network is likely to be the greatest potential barrier to developing rapid charge infrastructure.
- Some installations may require a new substation which could cost up to £200,000, in addition to the cost of land to site chargepoints and a substation. Distribution Network Operators are not responsible for paying for upgrades, except in instances where they have demonstrated that it will benefit network users. If prospective chargepoint operators are expected to be responsible for the full upfront cost of any network reinforcement, it is unlikely that they will be able to produce a business case for installing chargepoints.
- TfL and the appropriate Distribution Network Operators should collaborate from the outset to manage rapid chargepoint installations and any necessary supply upgrades, including integrating chargepoints into new built environment developments where practicable.
- Subsequent to the initial (unpublished) draft of this report TfL has confirmed that it will identify and enable sites for the installation of charging infrastructure across the TfL, borough and private sector estates. Enabling works will include upgrades of power capacity and groundworks to make the site suitable for charge point installations.

Links with other research projects

Transport for London is undertaking a comprehensive research programme on likely ULEV growth in London and the infrastructure needed to support that growth. The Energy Saving Trust has been working on behalf of TfL on two of these projects:

- *Mapping rapid chargepoint locations for commercial vehicles in London*. This fleet mapping exercise builds upon EST and TfL's previous work together on the Plugged-In Fleets Initiative, and aims to map the potential chargepoint requirements of commercial fleets operating ULEVs in London. Telematics data from more than 2,000 vehicles operated by 26 fleets was analysed to identify those routes which could be completed using a suitable ULEV, and illustrative rapid chargepoint locations were specified. The report has identified 85 locations where rapid chargepoints would serve the movements of the fleets analysed (no discussions with potential hosts or site assessments have been undertaken).
- *Charging Requirements for Private Hire Vehicles in London*. This rapid chargepoint mapping project aims to identify potential locations for infrastructure to meet the needs of zero emission capable private hire vehicles in London. GPS data from c.1,900 private hire vehicles was analysed and operators interviewed to identify where rapid chargepoints would serve the movements of the vehicles analysed.

This research, alongside the results of TfL's PIN and stakeholder engagement work, will be used to inform the deployment strategy for rapid chargepoints in London.

Annex: Glossary of terms

Term	Definition
AC	Alternating current
All London drivers	All London (Green Badge) taxi drivers can pick-up passengers anywhere in London.
Battery electric vehicle (BEV or pure-EV)	A vehicle powered only by electricity. The vehicle is charged by an external power source and incorporates regenerative braking which helps to extend the available range.
CHAdeMO	A charging protocol for delivering a DC supply to plug-in vehicles. CHAdeMO is primarily used by Japanese vehicle manufacturers, including Nissan and Mitsubishi, as well as Citroen and Peugeot.
Charging event	The time when a vehicle is connected to a chargepoint while power is transferred
Combined Charging System (CCS or Combo)	A charging protocol for delivering a DC supply to plug-in vehicles. It is currently used by BMW and VW. Most American and European manufacturers, including Ford, General Motors and Porsche have indicated that they will use CCS.
Conventional hybrid	Vehicles primarily powered by petrol or diesel which also have a storage battery charged by regenerative braking. This stored energy is then used to drive an electric motor which can assist the conventional engine to drive the wheels or drive them entirely for a short distance (usually less than a mile).
DC	Direct current
Euro (3, 4, 5 or 6)	Increasingly stringent standards for the acceptable limits for exhaust emissions of new vehicles sold in EU member states.
Extended range electric vehicle (E-REV)	A vehicle which combines a battery, electric motor and an ICE. The electric motor always drives the wheels with the ICE acting as a generator when the battery is depleted.
Fast charging	Charging a plug-in vehicle at typical rates of 7kW AC, 20kW DC or 22kW AC
Geofencing	A software feature that uses (GPS) to define geographical boundaries.
kW	Unit of power
kWh	Unit of energy
MAQS	Mayor’s Air Quality Strategy
Mennekes (Type two)	The recommended standard for public 3.5kW and 7kW AC chargepoints. It can also be used for fast AC charging at 22kW or rapid AC at 43kW.

NOx	A generic term for nitric oxide, nitrous oxide and nitrogen dioxide.
On-board charger	Systems on-board plug-in vehicles which use a rectifier circuit to transform alternating current (AC) to direct current (DC).
Open Charge Point Protocol (OCPP)	A protocol which allows chargepoints and central control systems from different vendors to easily communicate with each other
Opportunity charging	Re-charging a plug-in vehicle during daily use (rather than overnight at home or depot). Typically requires a fast or rapid chargepoint.
Plug-in car grant / plug-in van grant	Grant funding to support private and business buyers looking to purchase a qualifying ultra-low emission car or van.
Plug-in hybrid electric vehicle (PHEV)	Similar to a conventional hybrid, with a larger battery and the ability to charge the battery from an external power source.
PM (10 and 2.5)	Suspended particulate matter categorised by the size of the particle (for example PM10 is particles with a diameter of less than 10 microns).
Private hire operators / vehicles	Operators licensed by TfL including minicab, executive car and chauffeur-driven services. Private hire vehicles cannot be hailed in street and must be pre-booked with a licensed private hire operator.
Rapid charging	Charging a plug-in vehicle at typical rates of at least 43kW AC or 50kW DC
Regenerative braking	Converting the kinetic energy of the car into electricity which is stored in the battery.
Slow or standard charging	Charging a plug-in vehicle at typical rates of no more than 3.5kW AC
Source London	A network of publicly available chargepoints in London.
Suburban drivers	Suburban (Yellow Badge) drivers can only pick-up passengers in outer London areas.
Taxi	Black cabs licensed by TfL which can be hailed in the street or from one of around 500 ranks situated at prominent places including rail, Underground and bus stations.
TCO (total cost of ownership or whole life cost)	The full cost of owning or operating a vehicle, including purchase / lease cost, fuel, tax, insurance and residual value.
Ultra Low Emission Zone (ULEZ)	A scheme to help reduce the impact of road transport on London's air quality
Zero emission capable	Vehicles which are able to operate with zero or near zero tailpipe emissions.