Transport Energy Infrastructure Roadmap to 2050

ELECTRICITY ROADMAP

Prepared for the LowCVP by Element Energy Ltd
Celine Cluzel & Alastair Hope–Morley

JUNE 2015




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Project Steering Group

Autogas Limited
BEAMA
BOC Limited
Calor Gas Ltd
EDF Energy
Electricity Networks Association
National Grid
Office for Low Emission Vehicles
Renewable Energy Association
Transport for London
Transport Scotland
UK Petroleum Association

Acknowledgements

The LowCVP, established in 2003, is a **public-private partnership** that exists to **accelerate a sustainable shift to lower carbon vehicles and fuels** and create opportunities for UK business.

The LowCVP aims to:

- Develop initiatives to promote the sale and supply of low carbon vehicles and fuels
- Provide input and advice on Government policy
- Provide a forum for stakeholders to share knowledge and information
- Ensure that UK motor, fuel and related businesses are best placed to capitalise on the opportunities in the low carbon markets of the future
- Contribute to the achievement of UK Government targets for road transport carbon reduction

Project Steering Committee

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BOC Limited
BEAMA
Calor Gas Ltd
EDF Energy
Electricity Networks Association
National Grid
Office for Low Emission Vehicles
Renewable Energy Association
Transport for London
Transport Scotland
UK Petroleum Association

Workshop attendees

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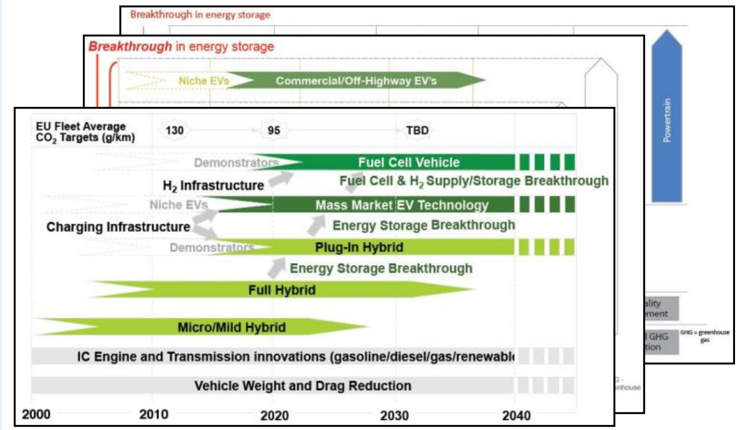
Tower Transit
UKLPG
UKPN
ULEMCo
UPS
Wales & West Utilities

Contents

Background - a 'Transport Infrastructure roadmap' is needed to complement existing vehicle and fuel roadmaps

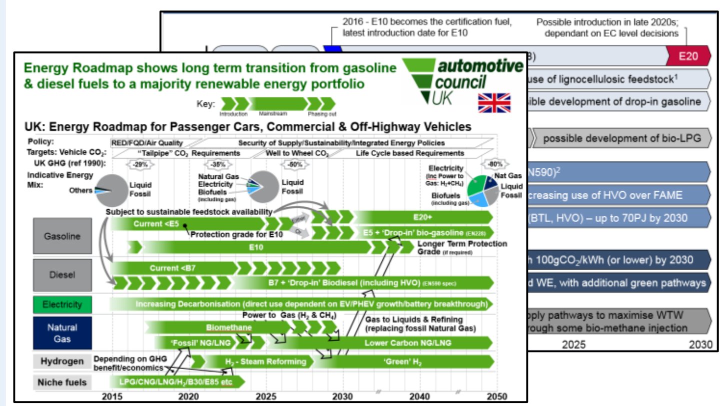
- In the context of the expected transition to lower carbon powertrains and fuels, the **Auto Council vehicle roadmaps** have proven to be a useful tool **to focus research, funding and policy**, bringing into one place the industry's views on future technology options, deployment steps and corresponding policy drivers.
- To complement these powertrain technologies roadmaps, the **LowCVP commissioned a Road Transport Fuels Roadmap in 2013-14,** which also proved successful in bringing clarity to the fuel options available and mapping the enabling milestones.
- This Infrastructure roadmap is the 'missing piece' that will support new powertrains and new fuels. This roadmap is all the more necessary as the **needs and barriers for deployment of electric, hydrogen and gas refuelling stations differ significantly** and refuelling/recharging infrastructure is a key enabler for low emission vehicles.
- The objectives of the Infrastructure Roadmap are to:
  - **Assess the infrastructure needs** and barriers for deployment of electric, hydrogen and gas refuelling stations to 2050, including impact on upstream distribution, as well as to consider 'conventional' liquid fuels
  - Make **recommendations for delivery** of infrastructure deployment, both at national and local government level.

Vehicle roadmaps



Source: Auto Council and LowCVP

Transport fuel roadmaps



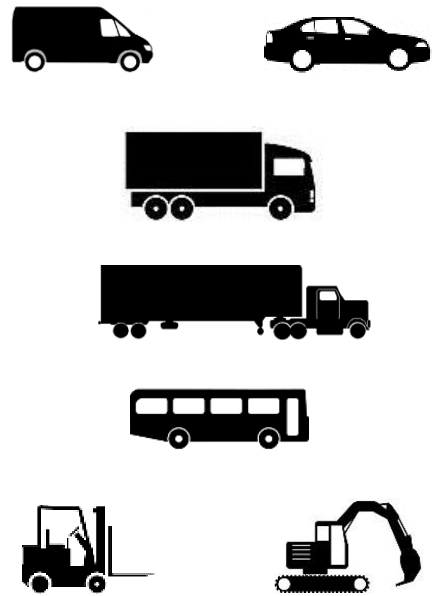
Source: Auto Council and Element Energy for the LowCVP

The Infrastructure Roadmap covers private and public infrastructure, for all main road vehicles and both current and future fuels

Fuels / energy vectors considered

- Zero tailpipe emission fuels: **electricity and hydrogen**
- 'Conventional' **liquid fuels**: gasoline (E5 to E20, in line with the Transport Fuels Roadmap), diesel, LPG/bio-propane
- **Methane**: Compressed Natural Gas (CNG), Liquefied NG (LNG) and biomethane
- Niche/future fuels: methanol, liquid air and a high bioethanol blend (E85)

Vehicle types



Refuelling infrastructure types

- Depot based refuelling for fleet operators and return to base operators
- Home recharging for private and (some) commercial vehicles
- Public forecourt refuelling/recharging

Drivers for change in the transport energy system

- The UK's legally binding target to **reduce total GHG emissions by at least 80% (relative to 1990 levels) by 2050**, and transport contributes to c. 25% of UK total GHG emissions;
- EU level regulations (gCO_2/km, **Air Quality targets** and EURO spec), Directives (Renewable Energy, Fuel Quality, Clean Power for Transport) and Transport White Paper

Source: Element Energy

The development of the Infrastructure Roadmap benefitted from input from a wide range of stakeholders, many consulted through workshops

Develop uptake scenarios for % sales of electric and ICE vehicles

ICE vehicles: diesel, petrol, LPG, gas vehicles
Electric vehicles: Battery (BEV), Plug-in Hybrid (PHEV), Range-Extended (RE-EV) and hydrogen fuel cell (FCEV)
Niche/future fuels considered: E85, methanol, liquid air

Input into Element Energy fleet model

Scrappage rate, stock and mileage inputs based on **DfT data/projections: c. 40% increase in stock and vkt by 2050 (39 million vehicles, 740 billion vkt)**; Vehicle efficiency based on **Committee on Climate Change modelling**

Output numbers of vehicles in the fleet and MJ used per energy vector

See full reports for further details of fuel uptake scenarios

Review existing literature on refuelling and upstream infrastructure

Industry consultation with LowCVP Fuels working group

Prepare Infrastructure Roadmap

Four dedicated fuel workshops were conducted

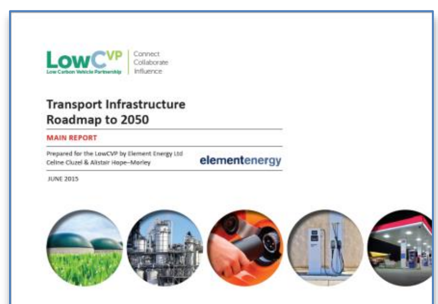
- Workshop themes: **electricity, liquid fuels, methane, hydrogen**
- **38 attendees included**: Infrastructure manufacturers, installers, operators, DNOs, energy companies, fuel suppliers, OEM / vehicle suppliers, end users, local government / regulator

Host stakeholder workshops

Review by Steering Committee

Prepare draft report

Complete final report

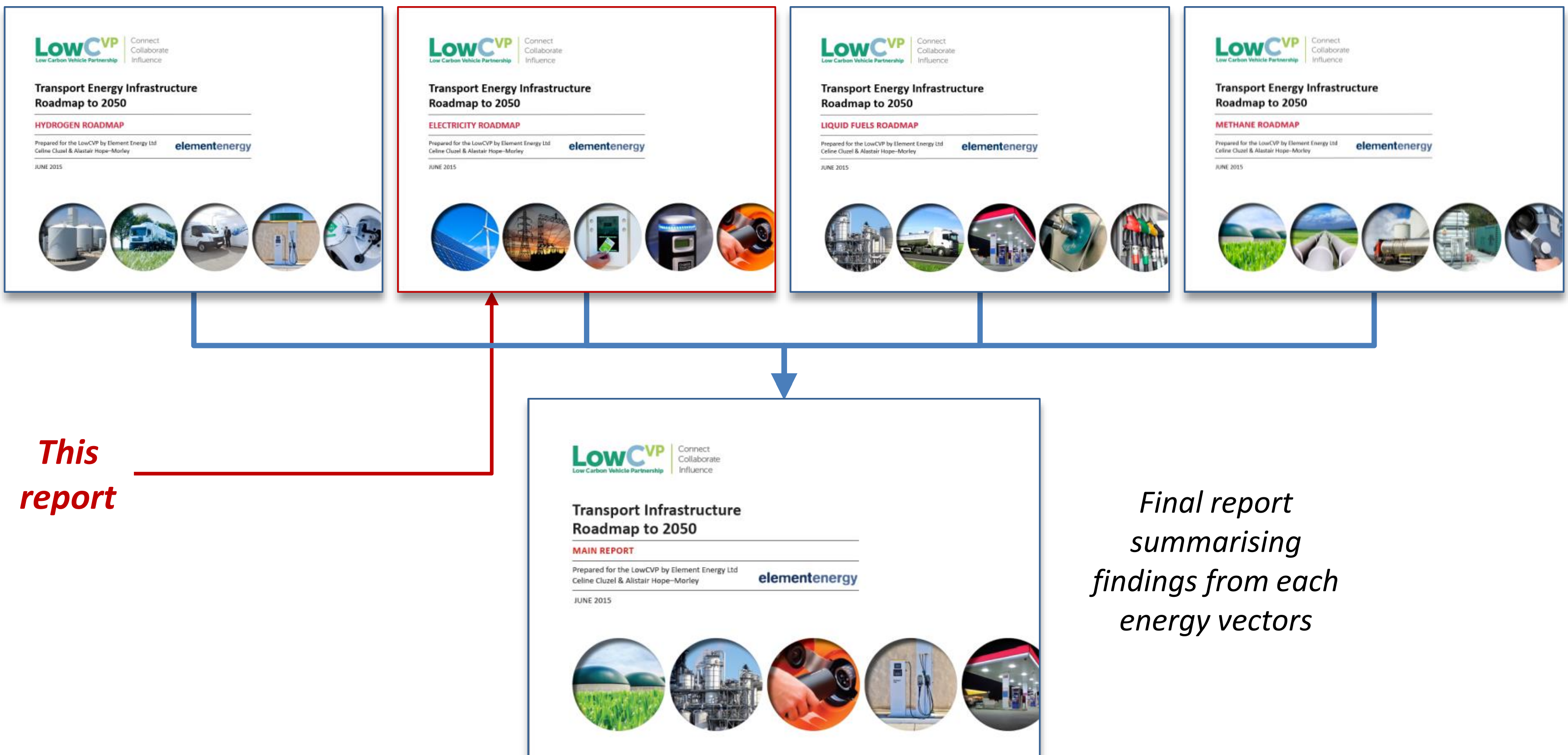


Report preparation

External input

Four separate reports have been developed – this report is dedicated to the case of electricity as a transport fuel

Four separate reports were produced to capture the differences between the energy vectors / fuels under consideration

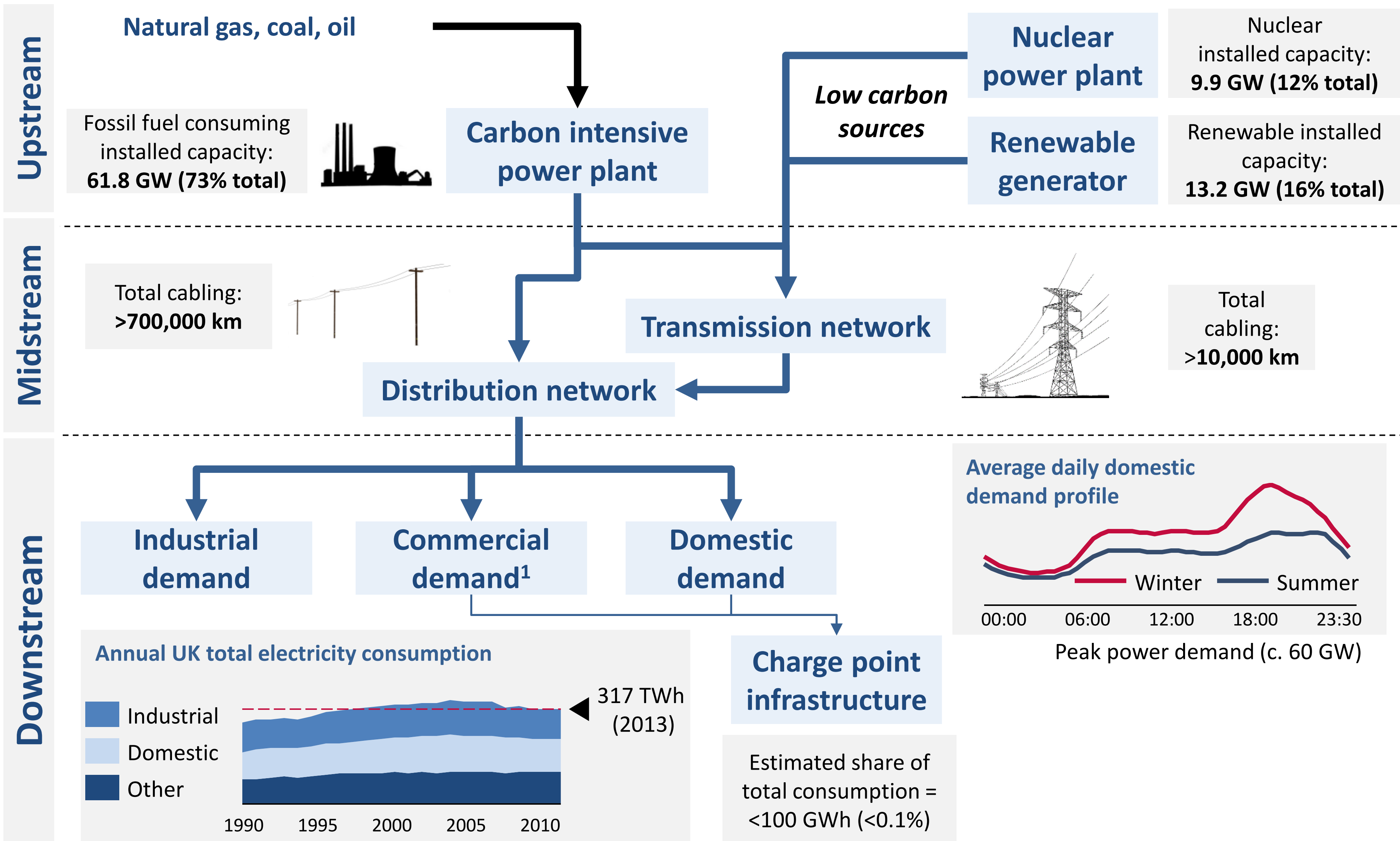


Structure of the report

- **Background and status quo**
  - Summary of current transmission & distribution system and energy vector usage
  - Energy vector current supply pathways
  - Current recharging technologies, geographical spread and key stakeholders
- **Future infrastructure requirements and barriers to deployment**
  - Quantification of charge point needs, per location and/or vehicle segments - based on projected demand, derived from validated uptake scenarios
  - Barriers to deployment of infrastructure - *barriers to deployment of corresponding powertrains are not discussed– uptake of new powertrains/fuels is the starting assumption*
- **Future power demand and network impacts**
  - Quantification of future EV peak power and energy demand under current diversity factors and associated mitigating for actions
  - Beneficial services EVs could provide through synergies with the grid
- **Summary roadmap and recommendations**
  - Roadmap schematic summarising the above findings
  - Recommendations for delivery (national, local, RD&D needs, funding shortfall)

Contents

The national electricity grid provides an existing distribution pathway for supplying power to electric vehicles across the UK

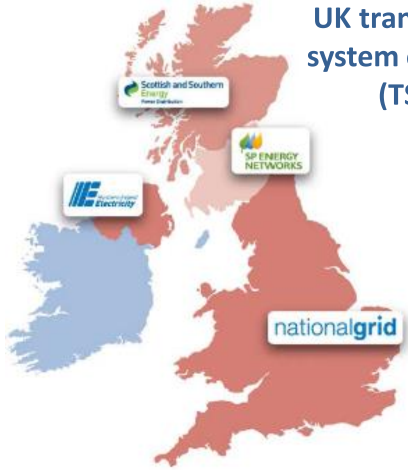


Source: DUKES Chapter 5 (2014), National Grid (2014)

[1]Includes public administration, transport, agricultural and commercial sectors.

Transmission and distribution networks aim to facilitate the most cost effective energy transfer from generation sources to demand centres

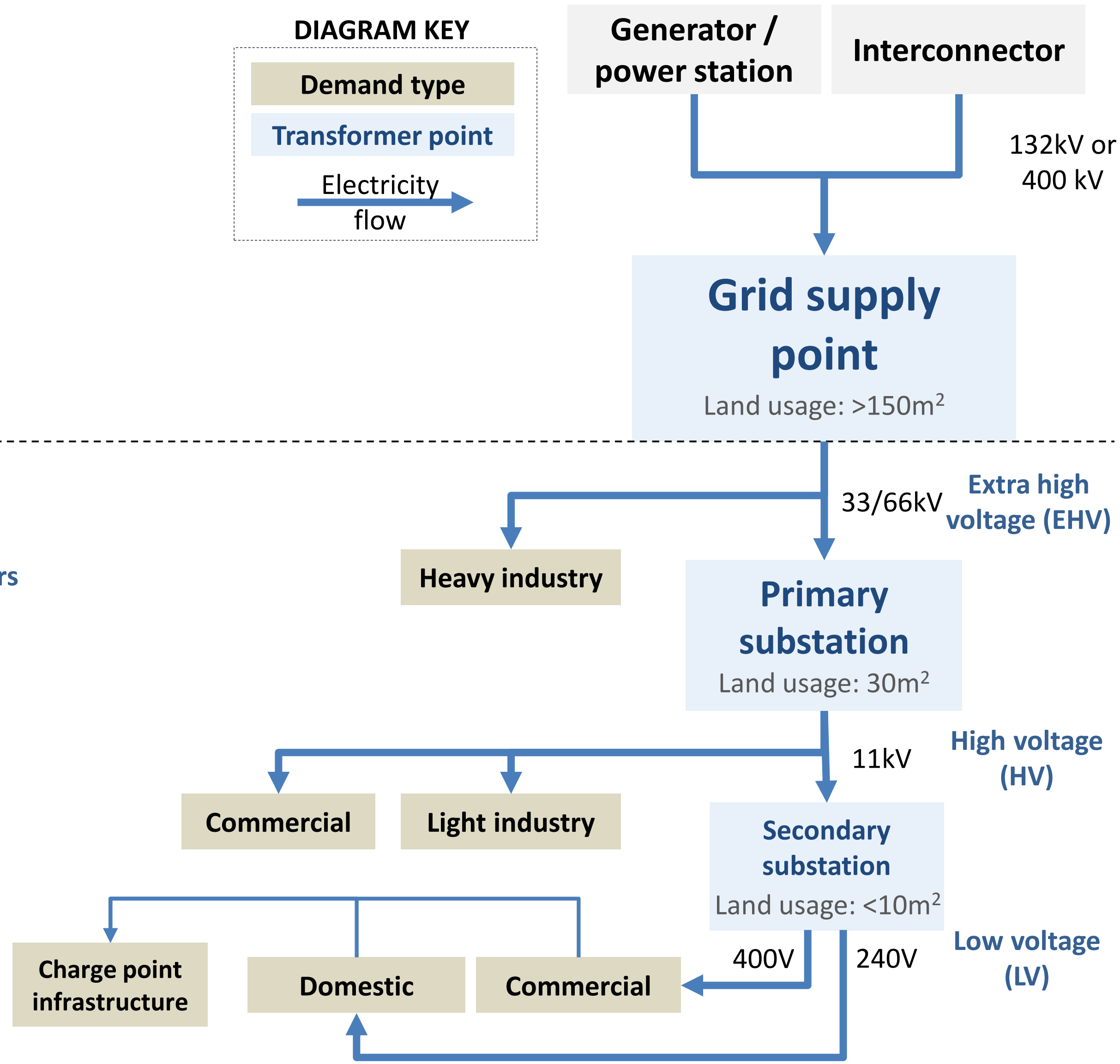
Transmission



UK transmission system operators (TSOs)

Distribution

UK distribution network operators (DNOs)



Source: National Grid, ENA (maps)
Generators connected to the EHV, HV and LV network are not represented on this diagram

The rollout of charging infrastructure in the UK has benefitted and continues to benefit from government support

Plugged-in-Places scheme (OLEV)

- £30m match-funding for CP installation made available
- Allocated to eight cluster regions; initially London, North East and Milton Keynes, then Northern Ireland, Scotland, Greater Manchester, Midlands and East of England
- Successfully unlocked private investment (only 30% of existing CPs are PiP funded)

Office for Low Emission Vehicles

European Commission issues 'Clean Power for Transport' Directive to harmonise alternative fuel infrastructure rollout

By February 2015, **c.8,000** public charge points had been deployed across the UK

2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015

Domestic recharging grant (OLEV)

- **February 2013**: £13.5m to subsidise 75% of CP capital cost
- **June 2014**: £9m to subsidise up to £900 of CP capital cost

Office for Low Emission Vehicles

New recharging grant (OLEV)

£32m for the 2015-2020 period:

- **£15m** for Electric Vehicle Homecharge Scheme
- **£8m** for public charging infrastructure
- **£9m** for additional infrastructure requirements

Announced - Highways Agency to invest £15million to add "1000s of new charge points" on trunks roads. Target: 95% of the time, motorists will be no more than 20 miles from a charge point. To **be completed by 2020**

Sources: EC, OLEV

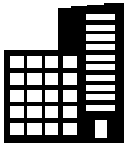
Three broad types of charging location exist for plug-in vehicles, with uneven level of utility between private and public charge points

Private – residential charging

- Mode 3 charge point installed in private garages / driveways
- Most common EV recharging infrastructure for **motorcycles, cars and vans**, largely due to cost (lower power requirement) and convenience (guaranteed access)
- 70% of households have a garage or off-street parking but this is as low as 10% in certain urban areas
- London Plan requires at least 20% of new premises to be "socket ready"

Private - work/ depot charging

- Charge points in workplace car parks / depots
- Only recharging infrastructure for electric **trucks and buses**; common for **cars and vans**
- Fitting several charge points in one depot can trigger the need to reinforce the local network – *an issue already reported by some operators*
- London Plan requires at least 20% of new premises to be "socket ready"



Public / semi-public charging

- Charge point installed on-street, in car parks, at retailers (e.g. dealerships supermarkets, restaurants), hotels, highway stations
- Generally low level of utilisation, with exceptions (e.g. where free parking is provided)
- Multiple type of access (various networks in place) and payment methods (roaming not widespread)
- The National Chargepoint Registry is a free database of public charge points published by OLEV

Home charging is the cheapest and most convenient way to charge an electric car, with potential to reach c. 19 million households

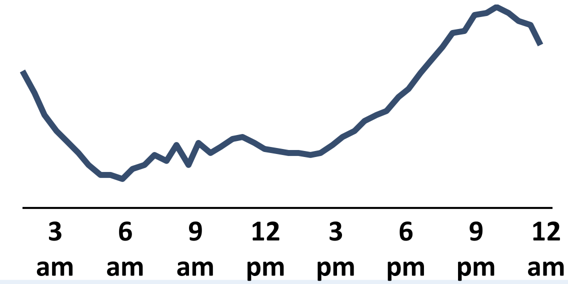
Technology	▪ Currently 3-7kW Mode 3 charge point with embedded safety features, can be tethered ▪ Future technology: wireless pads?
Cost	▪ Unit cost including installation up to **£1k** (and 75%/£700 grant available for accredited suppliers). Most OEMs have partnership with an utility / installer ▪ At 10p/kWh, charging costs **c. 2p/km** for a medium sized car
Utility and potential	▪ Certainty of access to charging is a pre-requisite to purchasing an EV. Over 90% of EV buyers have access to home charging ▪ c. 19 million (70%) households have off-street parking in the UK

Usage profile

Vehicles are plugged in mostly at night

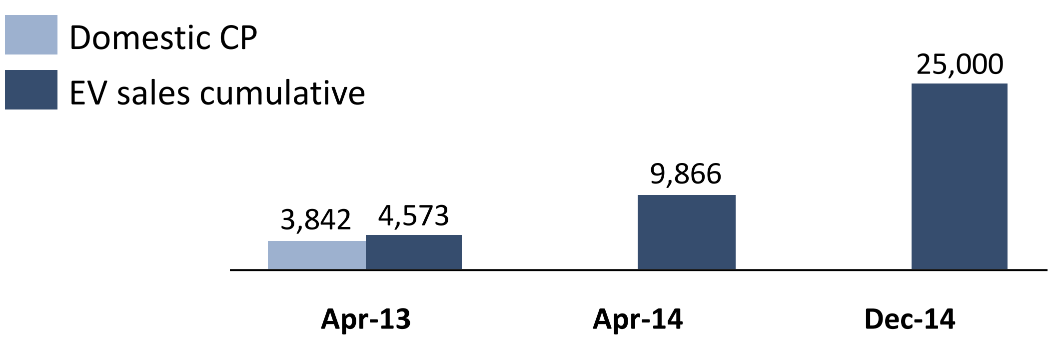
Average daily domestic demand profile[1]
Diversified peak 0.33kW, demand 3.68kWh

Peak demand at 9.30pm



Number installed

▪ Correlation between early domestic CP stats and sales of electric cars and vans suggest **over 30,000 domestic CPs have been installed by Feb 2015**



Depot charging is essential for heavy duty vehicles and some light EVs, with potential local network constraints more likely in short term

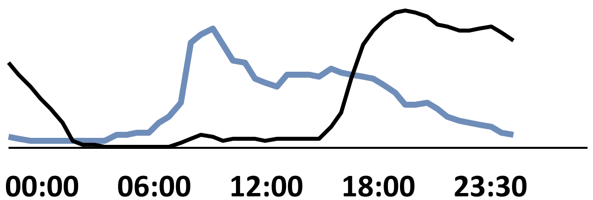
electricity

Technology	▪ Typically, Mode 3 charge points at 3 or 7kW used for light vehicles, generally Mode 4 observed for HDVs (typically at 50kW) ▪ Wireless charging for buses being trialled by TfL in London and Arriva in Milton Keynes
Cost	▪ Unit cost excluding installation **£750-£5,000** for Mode 3, **up to £30k** for Mode 4 points ▪ Installing several charge points can trigger a change in capacity charge and a need to pay towards the local network upgrade (**£10s to 100s thousand**)
Utility and potential	▪ Depot charging is essential for depot based vehicles ▪ Depending on future techno footprint & kW, same number of fleet vehicles using bunkered diesel could in theory be charging in depots in future

Usage profile

Varies with vehicle types (more limited data)

Average daily commercial demand profile[1]

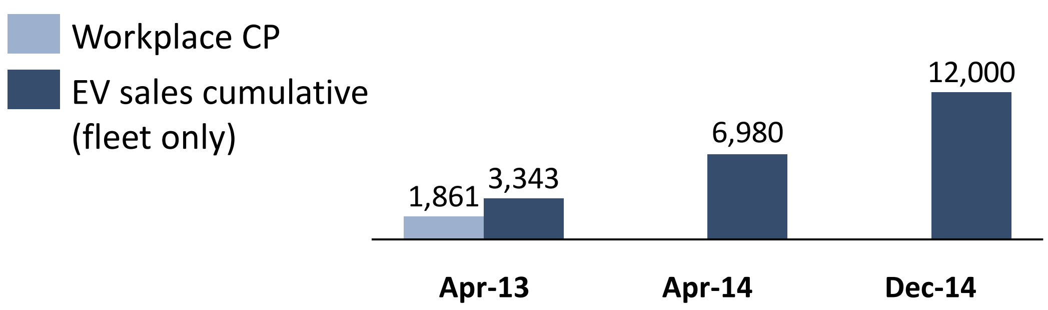


Peak 0.18kW, demand 1.53kWh - Peak at 10am

Peak 1.99kW, demand 17.4kWh - Peak at 7pm

Number installed

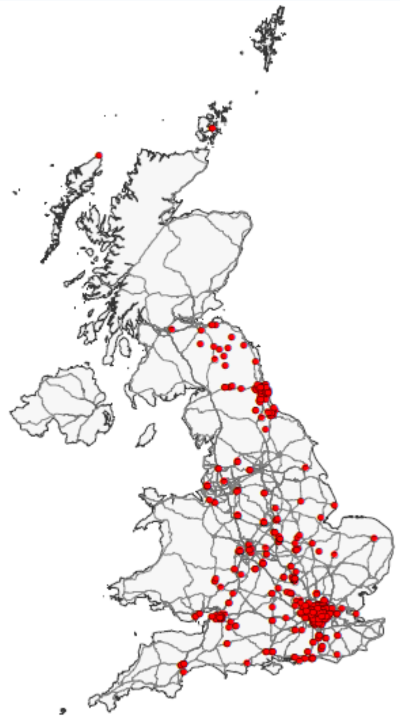
Ratio between early workplace CP stats and sales of fleet electric cars & vans suggest there might be **c. 7,000 CPs in workplaces** (some work EVs recharge at employees' homes only)



Source: Element Energy, DfT, OLEV. [1]UKPN Low Carbon London 2014 (week day demand, average over 16 EVs connected to 1-phase [mostly 3kW] and 10 vans connected to 3-phase [up to 14kW]) – profiles are scaled to fit in the same graph

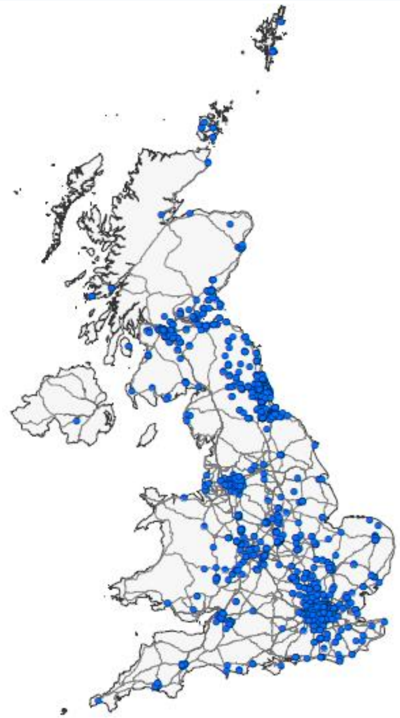
A firm public charge point infrastructure base has grown in the UK, with over 8,000 charge points installed at over 3,100 locations

Slow charge points
3 kW AC



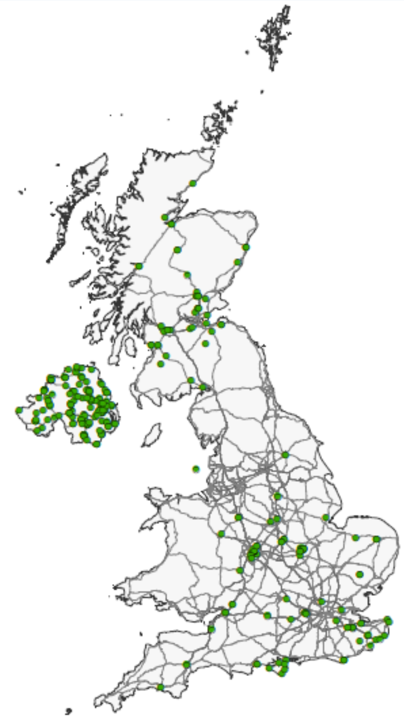
Mostly in public car parks and on-street

Fast charge points
7 kW AC



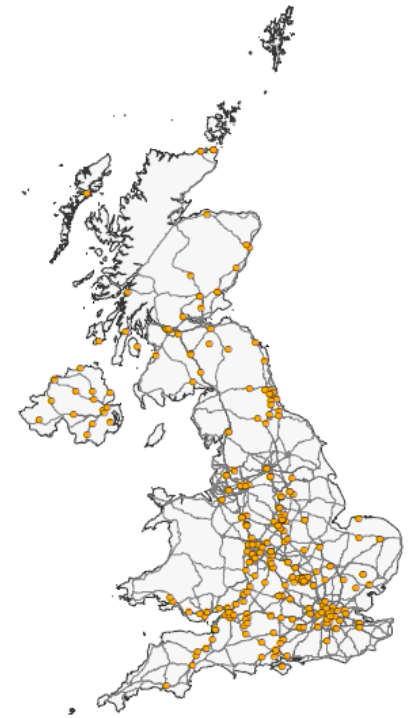
Mostly in public car parks and on-street

Fast charge points
22 kW AC



Mostly in public car parks, on-street and highway stations

Rapid charge points
43 kW AC- 50kW DC



Mostly at highway stations and car dealerships

Rapid network is due to expand with several agencies having recently announced investment in rapid charge point networks (detailed later):

TRANSPORT SCOTLAND

HIGHWAYS AGENCY

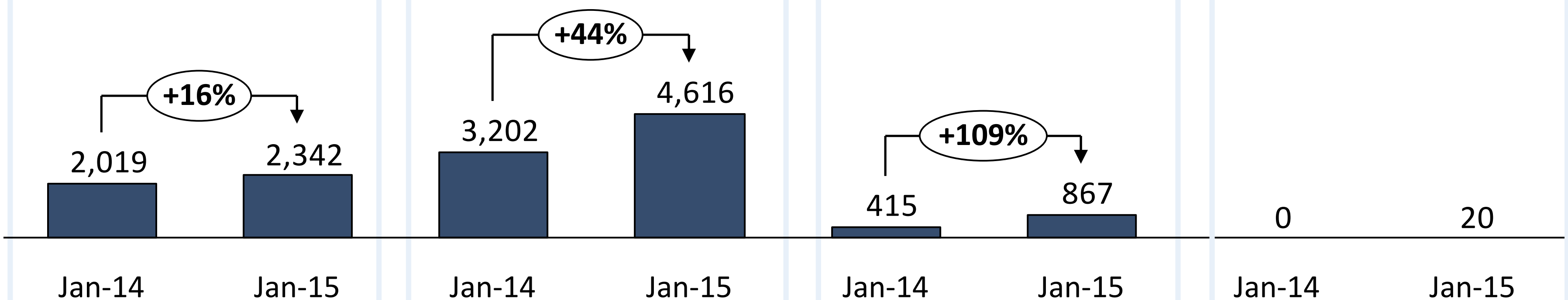
Maps created by Element Energy from OLEV National Charge Point Registry data as of January 2015

Public charge points come in a range of connectors and power rating, with a significant growth of fast and rapid units over the last year

electricity

	Slow charge points 3 kW AC	Fast charge points 7 to 22kW AC	Rapid charge points 43 kW AC- 50kW DC	Superchargers 135 kW DC
Outlet	▪ Varied – 3-pin sockets (c. 25%), Type 1 (disappearing minority) and Type 2 (dominant, EU standard)	▪ Mostly IEC 62196-2 type 2 (EU standard) ▪ 22kW requires 3-phase	▪ IEC 62196-2 type 2 for 43kW AC ▪ CHADeMO or CCS Combo for 50kW DC ▪ Requires 3-phase	▪ Compatible only with Tesla cars ▪ Requires 3-phase
Cost	▪ c. £10k on-street (Traffic Order needed, more process) ▪ <£2k off street	▪ Costs for 7kW similar/ close to 3kW ▪ Costs for 22kW: £12k-15k ▪ c. 80% are 7kW	▪ Costs for 43kW-50kW: c. £38-45k ▪ Can be higher if network upgrade is needed	▪ >> £50k ▪ High installation costs (network upgrade likely)

Number installed



Source: Element Energy, OLEV, Zap-map.com, teslamotors.com. Costs are indicative production +installation, connection costs will vary across sites. Number installed: number of outlets (number of locations is lower, typically 2 outlets/socket per location)

The numerous charging points are fragmented over several networks and do not offer a harmonised customer experience

electricity

Slow charge points 3 kW AC	Fast charge points 7 to 22kW AC	Rapid charge points 43 kW AC- 50kW DC	Superchargers 135 kW DC

- 5 national networks:

	charge your car	pod POINT	POLAR	ecotricity	ZERO CARBON WORLD
Swipe card	£20/year	£12.5 for life	£12/month or £20/year	free	n/a
App	Yes	Expected 2015	yes for PAYG	-	n/a
Fee	Some points free, some PAYG	Free; PAYG expected 2015	Point dependant	free	At the discretion of point owner
# points	>2,000	c. 1,000	> 4,000	> 220 rapid CP sites on highways	c. 600

TESLA

- No access card required
- Free for all drivers with Tesla vehicle purchased from April 2015
- 20 points

- A transition from a swipe card access to the use of mobile apps (providing anyone with access to the charge point) has recently started. However the multiple connectors and uneven deployment of PAYG apps still means the c. 8,000 points installed do not form a consistent network for users
- 7 regional networks - as with national networks, access type and fee are variable. PAYG is rarely offered:

source LONDON | source EAST | source WEST | Plugged-In Midlands | GMEV | energise network | e-car Charged for Success

Source: Zap-map.com, zerocarbonworld.org
CP: charge point PAYG: pay as you go

Not all charging rates can provide adequate charging times and compatibility varies across PHEV/BEV (and brands)

electricity

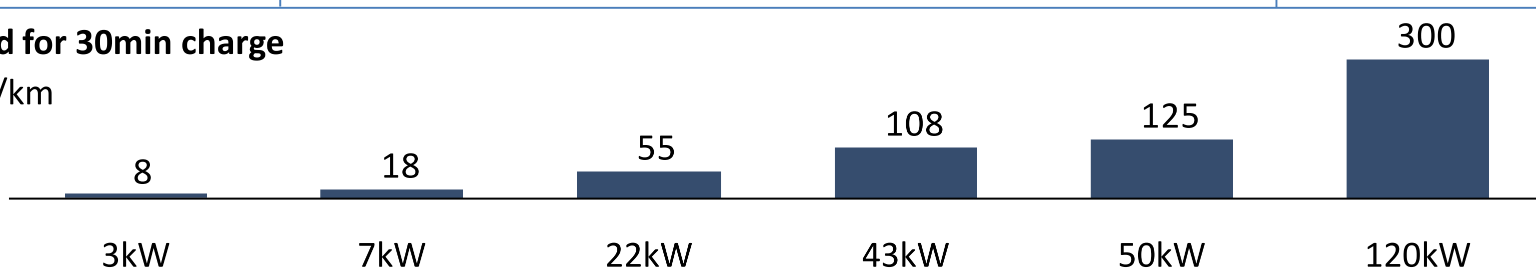
- As EV users predominantly charge at home/work, overall public CP usage is low (although average figures hide some high use cases, as many points are not used at all (out of service, old connectors, no PAYG options etc.). On-street charge points see the lowest usage whereas high rate intercity charge point usage is fast increasing
- However, a widespread charging network is perceived as essential for mass uptake of EVs. Even consumers most likely to buy an EV report the need for rapid public charging infrastructure to adopt these vehicles[1] – a fact reflected by consumers consistently reporting the limited driving range as a significant barrier to adoption
- Moreover, network operators indicate that average mileage of current EV drivers is higher than the national average, placing greater importance on the need for intercity rapid charge point infrastructure

Compatibility / utility - based on today's electric vehicles

	3 – 7 kW AC	22kW AC	43 kW AC - 50kW DC	135 kW DC
PHEV/ RE-EV	Adequate power rating	• Can connect to Type 2 AC outlet but on-board charger limited to 3kW or 7kW • Only one model fitted with a rapid DC charging port		Unsuitable power for vehicle type
BEV	Power rate adequate only for long parking times	• Enables long distance driving for light vehicles but charging still too long for very long distance (30min every 50-130km) • Adequate for long parking times for buses and trucks		Suitable power rate for long distances

Km range obtained for 30min charge

Assuming 0.2kWh/km



Source: Element Energy 1 – Around 75% of Enthusiasts and 80% of Aspirers reported a need for rapid charge points – survey on 3,000 new car buyers conducted in 2010 for the ETI

The business case of public rapid charging is currently challenging in the UK, suggesting a need for continued capex support

- High rate charge points, to complement home/depot charging, are the most valuable charge points to BEV drivers in providing ‘range extension’ and enabling longer journeys.
- The business case is however currently challenging in the UK:
  - **Difficult to attract paying users to areas where rapid charging is offered for free** (e.g. Ecotricity network)
  - **Travel patterns imply a low level of usage**: only c. 2% of daily total driving distances are over 160km. Even a higher estimate of each BEV using a rapid charge point once every 2 weeks[1] gives an overall low usage:
    - C. 12,000 pure electric cars and vans on the road today, charging once every 2 weeks, gives 860 charging events a day on average
      - Over 870 rapid charge points, that’s **1 charging event/outlet per day on average**
      - Over 1,800 rapid + fast charge points, that’s **0.5 charging event/outlet per day on average**
  - **Observed typical capex and opex suggest a fee of £5/30min event must be collected 6 times a day to get a positive Net Present Value over 10 years** (assuming low costs: £50k capex & installation, £800/year for back office & maintenance and 7p/kWh, no cost for land leasing)
    - Highest fee observed for a rapid point is £7.5 for a 30 min charge (Chargemaster PAYG fare); this corresponds to c. 6p/km, equivalent to diesel cost (with diesel at £1.14/l and 5l/100km consumption)
    - At 50% capex funding, pay back can be achieved within c. 5 years
  - In some areas, installing a 50kW load or more can lead to expensive network connection costs or/and upgrade
- However countries where EV uptake is higher provide examples of commercially run rapid charging networks e.g. 100% privately funded Fastned network (Netherlands), Charge & Drive (Norway and more, partly publically funded)

Source: Element Energy, National Travel Survey, petrolprices.com accessed 16/02/15, chargemasterplc.com

1 - Dutch CP average usage calculated from survey answers (“Resultaten enquête snelladen” by Agentschap, March 2012; n=45)

In 2014, the European Commission issued a directive to help harmonise technical specifications for electric vehicle charge point infrastructure

- The **Clean Power for Transport** program, initiated in 2013, aims to facilitate the development of a single market for alternative fuels for transport in Europe
- The resulting **2014/94/EU directive** on 'the deployment of alternative fuels infrastructure' aims to:
  1) Harmonise technical specifications for recharging and refuelling stations
  2) Develop clear, transparent fuel price comparison methodologies
  3) Ensure Member States develop national policy frameworks to support the deployment of alternative fuel technologies and infrastructure

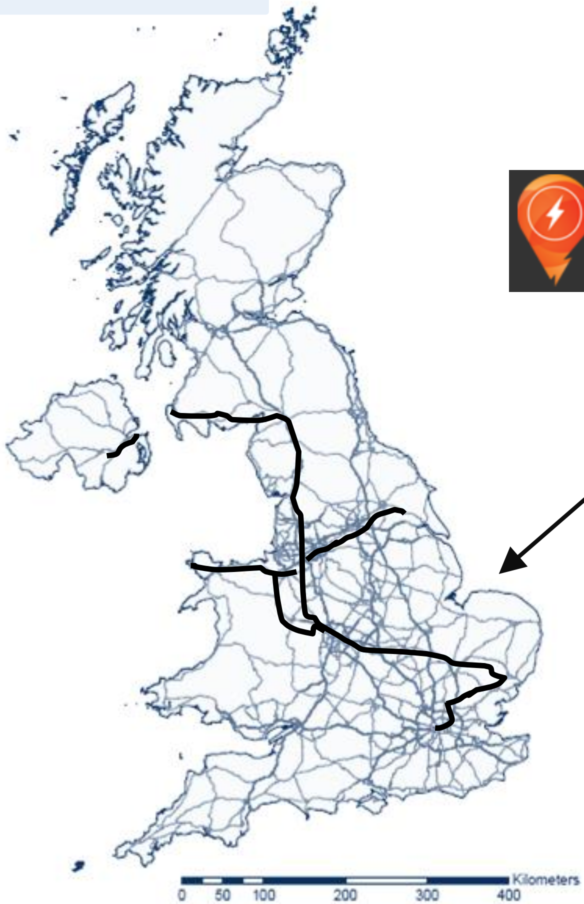
From Nov 2017, all CPs deployed or renewed in the EU must be compliant with the technical specification

AC normal and high power charge point installations	**EN 62196-2** All new CPs must include a Type 2 connector
DC high power (>22kW) charge point installations	**EN 62196-3** All new DC high power CPs must include a Combo 2 connector
Intelligent metering for DSR purposes should be incorporated if not economically or technically prohibitive	**Directive 2012/27/EU** Intelligent metering systems must be compliant
Interactions between charge point infrastructure and the electricity system	**Directive 2009/72/EU** Ensuring an operator/supplier competitive market and an end-user/operator transparent, non-discriminatory pricing system
Public charge point infrastructure national network coverage	Appropriate no. of public CPs[1] must be installed along the TEN-T network and in urban/suburban areas by the end of 2020
Future technology developments and breakthrough	Directive will be amended to facilitate future technical innovation needs (e.g. emergence of battery swapping facilities)

[1]As an indication, the appropriate average number of recharging points should be equivalent to at least one recharging point per 10 cars, also taking into consideration the type of cars, charging technology and available private recharging points

The rapid network is due to expand with several agencies having recently announced investment in rapid charge point networks

Rapid charge points
43 kW AC- 50kW DC



TRANSPORT SCOTLAND

Transport Scotland is targeting a rapid charge point every 35 miles

rcn rapid charge network

- **The Rapid Charging Network project**
- Development of the multi-standard rapid charge point
- Up to 74 rapid charge points installed (29 as of Feb 2015) along the full length of the EU's Priority Project Road Axes 13 and 26 throughout the UK and Ireland (1,100km)
- Supported by 4 OEMs (Nissan, Renault, BMW, VW)
- Study of business model and dissemination of results

Co-financed by the European Union
Trans-European Transport Network (TEN-T)

- Highways Agency (England) has announced plans for a **charge point every 40 miles by 2020**, to be a "rapid charge point where possible"
- **£15m funding** announced in Autumn 2014, will be supported by an additional £8m from OLEV

HIGHWAYS AGENCY

Contents

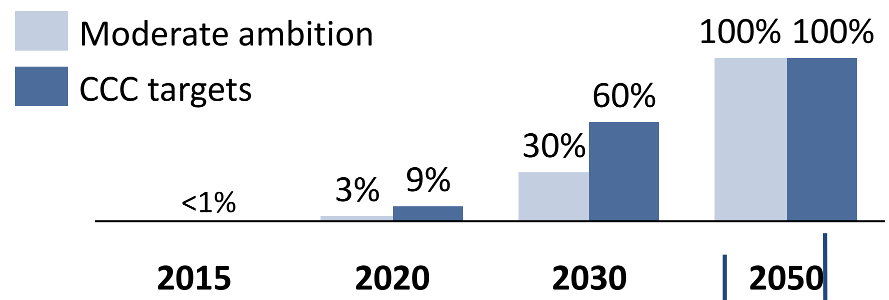
Transport electricity demand and corresponding need for charge points has been quantified based on projections of plug-in vehicle uptake

In consultation with the LowCVP Fuels Working Group, we derived uptake scenarios for new powertrains/fuels, they are policy led, typically based on CCC targets. Scenarios are used to forecast infrastructure required to match transport policy ambition and estimate the corresponding upfront costs of this infrastructure

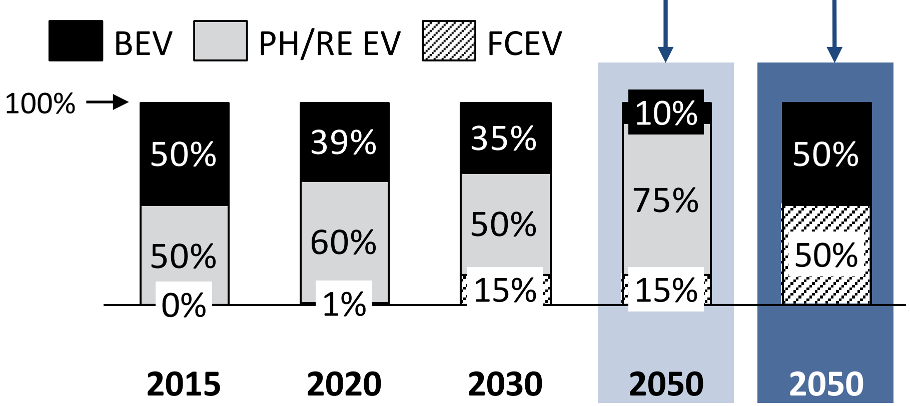
In the case of plug-in vehicles, uptake is mainly in the light vehicle segments

- **Two scenarios** for cars & vans,
  - '**CCC targets**': EVs reach 60% market share by 2030 and Zero Emission vehicles reach **100% of market share before 2050**
  - '**Moderate ambition**': the 2030 CCC targets are not met but EVs uptake is nonetheless high (30% new sales); by 2050 **EVs represent 100% of sales but are mainly PHEVs or RE-EVs**, i.e. still reliant on liquid fuels
- A increase of sales of **plug-in buses** to 2% in 2020, 5% in 2030 and 40% in 2050
- A increase of sales of **plug-in trucks** (mostly under 7t GVW) to 1% in 2020, 5% in 2030 and 20% in 2050

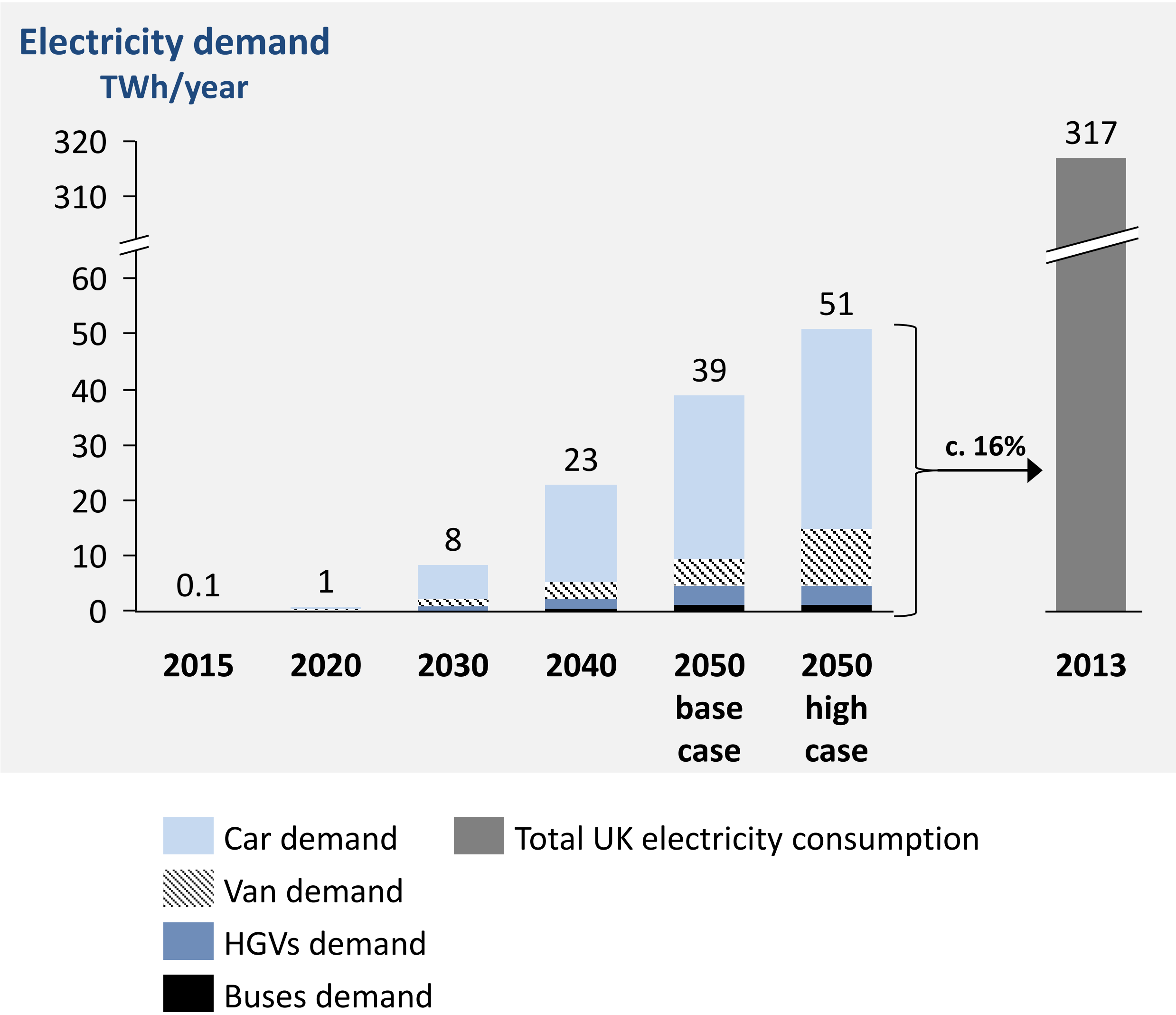
Market share of EVs (new sales)

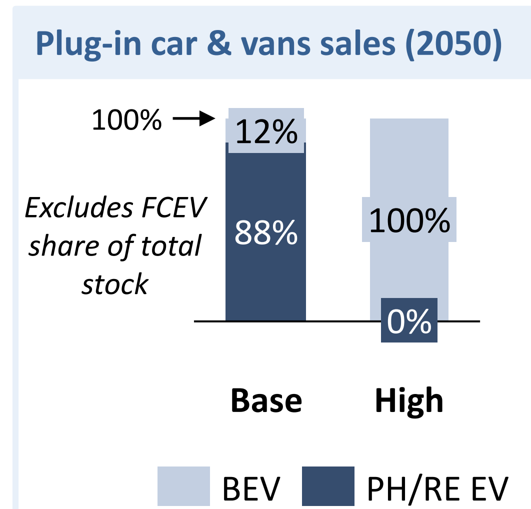


Breakdown of market share of EVs



A successful high penetration of plug-in vehicles could add 16% (c. 50 TWh) to the electricity demand compared to today's use





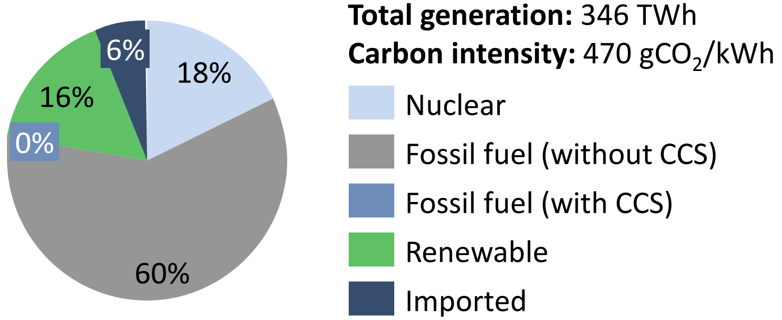
Base case includes mainly PHEV and RE EVs whilst the high case assumes 100% pure EV sales by 2050

Efforts to decarbonise the power sector could see 50-70% of total electricity generation sourced from low carbon assets by 2035

The UK generated 34% of total electricity consumption from low carbon resources in 2013

UK actual electricity generation composition (2013)

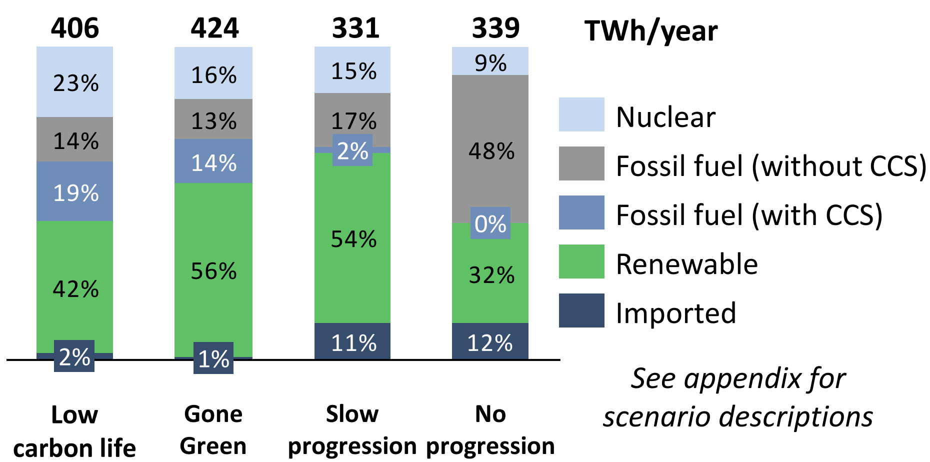
Total generation: 346 TWh
Carbon intensity: 470 gCO_2/kWh



- The UK has **invested £45bn in electricity generation and infrastructure** since 2010
- 16% of this was invested in renewable assets in 2013 alone, a 60% increase on 2012 renewable investment levels
- Overall energy investment makes up c. 60% of the National Infrastructure Plan's budget (c. £470 billion) – *future provision is in hand*

National Grid has developed multiple electricity generation supply scenarios

UK predicted electricity generation composition (2035)



See appendix for scenario descriptions

	Low carbon life	Gone Green	Slow progression	No progression
gCO_2/TWh	**63**	**40**	**79**	**238**
Change compared to 2013	*-86%*	*-91%*	*-83%*	*-49%*

- New generating capacity investment decisions, addressing increased demand from electrification of heat and transport sectors will be **governed by cost, security of supply and environmental impact**
- Scenarios consider combinations of **high renewable deployment** (onshore wind, solar, etc.) and/or **high low carbon technology deployment** (CCS, CHP, etc.)
- Innovation breakthroughs for unproven technologies needed (e.g. CCS and large-scale marine)

Source: National Grid "UK Future Energy Scenarios" (2014), HM Treasury National Infrastructure Plan (2013), DECC Energy Investment Report (2014). CCS = Carbon Capture and Storage, CHP = Combined Heat and Power

The current three distinct cases for dedicated EV overnight charging are expected to remain the main charging locations in future

Residential charging

- Majority of passenger cars and c. 60% of light commercial vehicles ('vans') are parked at home rather than at businesses[1]
- Vehicles have battery of typically 20-40 kWh and are inactively parked overnight for long periods of time (6-8 hours)
- Regular power charge point installation will be suitable (3-7 kW)

Depot charging (normal kW)

- Remaining c.40% of commercial vans and small fraction of passenger cars will be parked at the workplace overnight and will therefore be dependent on depot charging

Depot charging (rapid kW)

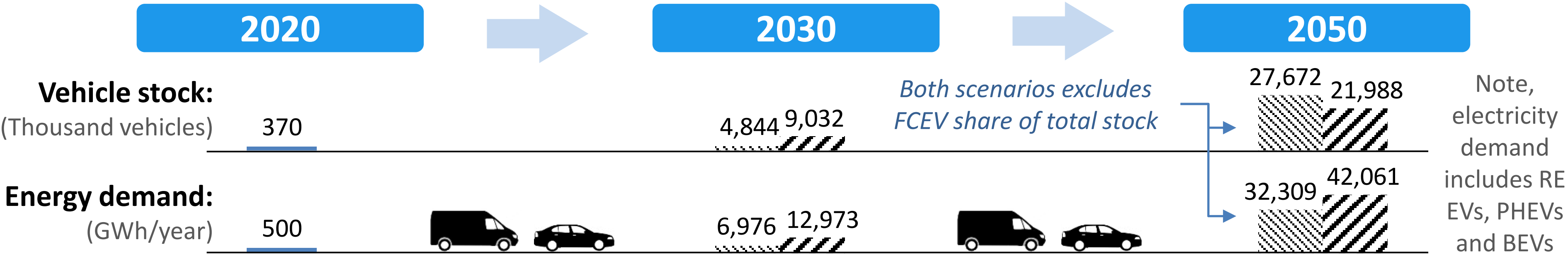
- Commercial HGVs and buses will be parked at depots after regular shift operation for battery recharging
- Larger HGVs and buses with much larger batteries (300-400 kWh) and energy consumption
- Higher power charge points will be required (>40 kW) to ensure full battery replenishment during brief windows of inactivity (<6 hours)

[1]See appendix for more detail

By 2050, over 80% of electricity for transport could be delivered via residential charging infrastructure

Electricity (Both scenarios)
Electricity (Moderate scenario)
Electricity (CCC target scenario)

electricity



Short/medium term

- Domestic charging must be prioritised due to **>95% lower cost relative to on-street charging**[1]
- Drivers without off-street parking (c.30% homes) must be supported
- Deploy recommendation from projects such as My Electric Avenue to minimise local network impacts
- Most EV demand occurring during system peak hours can be shifted towards late evening and night hours without detrimentally affecting EV state of charge
- Single vehicle households are a minority in the UK, but significant number of multi EV homes are not expected until post-2020
- **300k-370k CP off and on-street installations** could be expected by 2020 and 3.9 million (base) to 7.2 million (high) by 2030

Long term

- If not addressed, widespread issue of lack of off-street parking: based on current trends, 26 million households will have access to off street parking vs. 20-25 million plug-in vehicles on the road – but off-street provision is low in urban areas, where EVs are most incentivised / needed for air quality
- By 2050, multi EV households will be common and up to **10-15 million CPs could be installed** in on and off-street residential locations

Infrastructure investment must be flexible with respect to uptake of other low carbon transport fuels

[1]On-street must include weather proofing, access/payment system, traffic management order, etc.
Source: EE fleet model, based on uptake scenarios presented in Chapter 1 (Introduction and context)

<10% of electricity for transport could be delivered via 3-7kW power depot charging infrastructure

Electricity (Both scenarios)
Electricity (Moderate scenario)
Electricity (CCC target scenario)

	2020	2030	2050
Vehicle stock: (Thousand vehicles)	23	267 501	1,765 1,374
Energy demand: (GWh/year)	55	530 979	1,920 4,129

Note, electricity demand includes RE EVs, PHEVs and BEVs

Short/medium term

- Shift work and synchronised operation of commercial vans gives an **unfavourable diversity factor** (c. 85%) therefore requiring greater need for smart charging mechanisms to alleviate grid impact
- Moreover, **synergies between regular fleet operation and network management systems** could bring many benefits to the grid but relationship between fleet operators and DNOs need to be improved
- Availability of rapid charging during operational breaks could reduce range anxiety and potentially increase fleet substitution rates
- **8-10k CP depot and workplace car park installations** could be expected by 2020 and 100-200k by 2030[1]

Long term

- Battery and charge point efficiency improvements are unlikely to significantly affect EV demand diversity, instead charging management solutions will be required
- By 2050, operators with larger EV fleets will have fewer CPs per EV, therefore **400-550k CP installations could be expected**

Infrastructure investment must be flexible with respect to uptake of other low carbon transport fuels

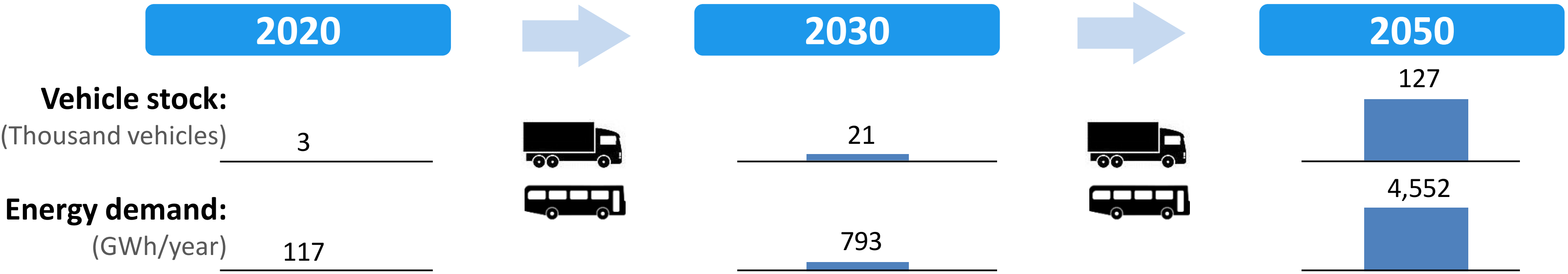
Source: EE fleet model, based on uptake scenarios presented in Chapter 1 (Introduction and context)
[1]Assuming an average of three vehicles per depot or three vehicles per charge point

Electric HGVs and buses will require high power charging infrastructure at depots

Electricity (Both scenarios)

Both base and high scenarios are the same for trucks and buses

electricity



Short/medium term

- **Only depot charging infrastructure** required
- Bus and (most) HGV operation follows regular routes making such vehicles well positioned to use **inductive charging facilities** (learnings from current trials in London and Milton Keynes will inform future infrastructure requirements)
- Moreover, recharging windows will be predictable but will be less flexible for engaging with smart charging mechanisms (e.g. Demand Side Response)
- Fleets wanting to adopt several electric buses/trucks will very likely face network reinforcement costs and lengthy procedures
- >75% of HGVs in the UK are part of small <6 vehicle fleets whereas bus operator fleets are considerably larger
- As such, 4-5k rapid CP installations could be expected by 2030

Long term

- **Battery swap infrastructure** for commercial fleets could provide a more cost effective option enabling lower power recharging
- **Ultra High power charging stations** (300-400kW) as trialled in Sweden might get deployed on bus routes
- Infrastructure to support heavy duty vehicle intercity travel might become necessary
- 20-25k rapid CP installations by 2050

Infrastructure investment must be flexible with respect to uptake of other low carbon transport fuels

[1]Assumes 86% diversity factor (LCL findings) and 50 kW CPs for all rapid power depot installations. Source: DfT "The Heavy Goods Motor Vehicle Fleet 2010-11", EE fleet model, based on uptake scenarios presented in Chapter 1 (Introduction and context)

Future public charging networks should focus on high charge rates and should be visible and accessible by all drivers and vehicles

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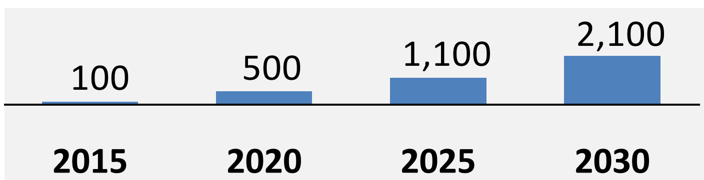
Public charge point infrastructure

- Normal CPs (3-7kW) are suitable for **long parking times** (e.g. overnight or at work) since 30-60km of range would require at least an hour of charge time
- Rapid CPs (40+kW) are **more expensive** but can charge **more vehicles in a given period** and offer **practical EV range extension** opportunities to users, thereby enabling drivers to achieve long distances (>200km) travelling at motorway speeds

Rapid charge points (40+kW) can create a useful network

- Rapid charge points should be:
  - **Well marketed to drivers** (e.g. clear signs, uniform signage across the UK)
  - **Easy to operate** (e.g. multi socket connections, simple payment system, etc.)
  - **Immediately accessible** (e.g. PAYG, development of dynamic booking systems, live status information)
- Estimated **2,100 sites** (10 charge points per site) could provide national coverage by 2030
- Best proxy for such sites is the private sector led Dutch Fastned network of rapid CP ‘forecourt style’ stations that reports a high level of usage

Total rapid charge point sites



Estimated total investment: £300-£530m[1]

Slower rates in cities

- Missing evidence on utility and/or business case of public charging for non-residents in cities (observed usage rate low so far, mismatch between power rate and parking time etc.)
- However, it is expected that some private businesses will (continue to) install charge points for their clients and/or visitors, e.g. retails, hotels, restaurants

SOURCE: CCC “Pathways to high penetration of electric vehicles” (2013), Fastned

[1]Based on current and projected unit costs for 50kW DC rapid charge points

The current conductive charge points might be complemented or superseded by other technologies in future

	Deployment status	Main barriers	Possible UK application
Static inductive charging	▪ Trialled in bus depots and bus routes	▪ Standardisation of power (and data/ payment) transfer protocol across vehicle OEMs ▪ High installation cost ▪ (Perceived) safety concerns	▪ **Home**: no high installation cost for a non buried pad, would facilitate home smart charging systems and improve driver experience; expected pre-2020 ▪ **Depot**/**taxi ranks/bus stops**: ease of use and reliability (vs. forgetting to plug in) valued by fleets; expected pre-2020
Dynamic inductive charging	▪ Highways Agency currently doing a feasibility study ▪ Deployed for buses in South Korea		▪ Allowing intercity travel for electric heavy duty vehicles i.e. on highways ▪ Unlikely before 2030
Battery swap	▪ Deployed with buses in China, vans in Slovakia ▪ Passenger car operator Better Place ended all operations in 2013	▪ Standardisation of battery packs across vehicle OEMs	▪ Possibly large commercial fleets, but not in short term
Overhead cable charging	▪ Existing technology	▪ Infrastructure costly to install & maintain	▪ Possibly for trolley buses in some cities
Ultra High Power	▪ Being trialled on buses (Sweden, Canada)	▪ Power supply/grid	▪ Possibly dedicated for buses and HGVs

Electrode replacement (as developed by Phinergy) would suffer from the same issue than battery swapping

Overnight low power rate is the most cost efficient charging mode but households w/o off street parking will require a dedicated solution

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Challenges	Description	Example solution
Overnight charging for users without off street parking	Capex for on-street charging has large premium over home systems and on-street charge points do not provide certainty of access	Research (e.g. into safety, land ownership, business case) is currently on-going (TfL and several London boroughs), Westminster City Council about to deploy a solution – *underway*
Non-owned home charge point	Tenants requiring home charging must pursue often lengthy negotiations with landlords	Tenants' rights to include installation of charge point; new housing requiring all parking spaces to include EV-ready sockets – *underway in Westminster City Council (WCC requires 100%, London Plan requires 20% spaces to be 'socket' ready)*
Car club vehicles	Car club vehicles are typically parked in residential areas, they will require some dedicated infrastructure to transition to electric powertrains	Install charge point at car club bay. Issues with using public sector funding to support commercial activities will need to be considered – *already underway in some places*
Employees charging company vehicles at home	Employers must be able to reimburse the electricity cost of company vehicles	IT solutions required – *already underway*
Charge point installed by employers	Employers might be reluctant to invest in home charge points as employee might move house / leave company	Give right to recover the charge point if employment contract not in place anymore
Sharing private charge points	End users may decide to share the cost of installing charge point(s)	Vehicle **identification systems** for infrastructure shared between several users

Fleets will need to invest in charging infrastructure with the risk of technology not being future proof

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Challenges	Description	Example solution
Cost of equipment and potential network upgrade	High charging rate for commercial vehicles means high capex and potential network upgrade costs (e.g. c.£1m network upgrade investment to support c.50 EV fleet at a single depot was needed in London)	Dedicated government support could help but issues of State Aid for commercial activities will need to be considered
Plan e-fleet expansion (generally non-incremental)	A depot owner wanting to make local network investment efficient with 'over-spec' to cater for future expansion of its fleet of EVs might have to pay capacity charge (p/kVA/day) to 'reserve' the capacity needed in future or take the risk of losing the extra capacity	DNOs to use the Enhanced Scheme (*see definition below*) in areas where fleets are clustered
Battery and charging technologies still improving	Infrastructure requirements are continually changing to support vehicle innovations (e.g. power rating, technology type)	Adopt simplest (most flexible and most inter-operable) solution on market, e.g. not relying on specific IT, and work closely with vehicle OEMs to select charging solutions

Definition of key terms of the **Common Connection Charging Methodology** that applies to DNOs

- **Minimum Scheme**: The scheme with the **lowest overall capital cost** solely to provide the required capacity.
- **Enhanced Scheme**: In certain circumstances the DNO may decide to design an enhanced scheme, with additional assets, assets of a larger capacity, or **assets of a higher specification than that required** by the minimum scheme. In this case, the person requesting the connection will be charged the lower of the connection charge associated with the minimum scheme or the connection charge associated with the enhanced scheme.

Source: Element Energy

A number of technical and commercial factors could be harmonised in order to improve end user experience of public infrastructure

Challenges	Description	Example solution
Recharge time	Electrochemical battery replenishment is inherently slower than regular vehicle refuelling	Match charge point charging rate to expected parking times – *underway*
Public charge point access	Queues for charging infrastructure can be inconvenient due to longer charge times	Requirement for **dynamic booking systems** and data logging to optimise future systems
Public charge point reliability	Cases of poor quality charge point technology and installation resulting in downtime worsened by poor communication of availability to drivers	**Incentivise private sector investment** thereby ensuring installation and maintenance is to a suitable standard
Charge point specifications	Adhering to OLEVs standards can be costly (e.g. must have three connectors), often making unsubsidised alternatives more cost effective for the case of fleets	Standards required for subsidy schemes to be more **flexible** in the case of charging points (mostly) **dedicated to fleets** such as taxis, car clubs, vans

A number of technical and commercial factors could be harmonised in order to improve end user experience of public infrastructure

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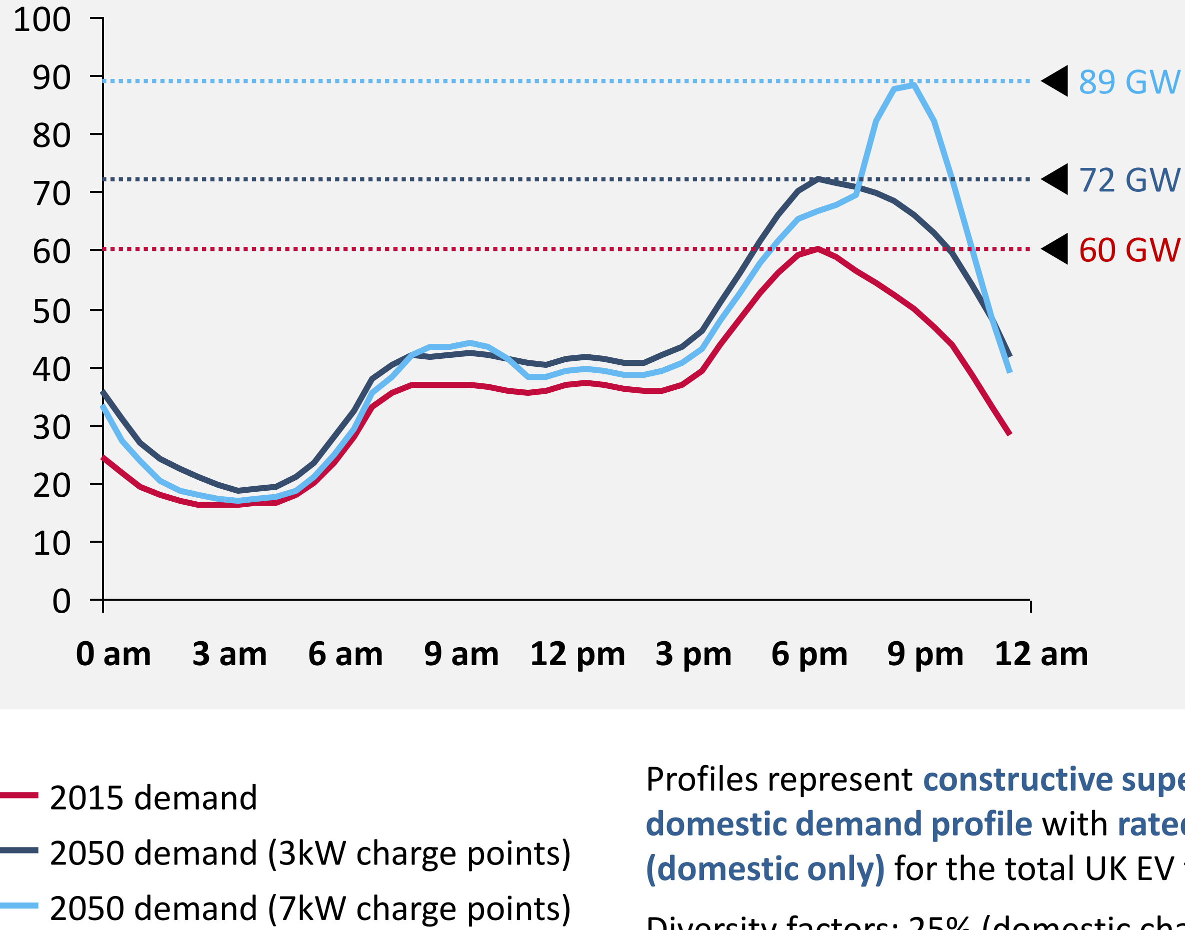
Challenges	Description	Example solution
Communication between EVs and infrastructure	In-car technology to communicate vehicle state of charge with infrastructure will improve operator understanding of user needs	Develop Vehicle-to-Application (V2A) and/or **Vehicle Infrastructure Integration** (VII) systems compatible across multiple vehicle types
Business model(s) for public charging infrastructure	Public infrastructure is operated via varying commercial arrangements – business case is challenging but ensuring private sector investment is key to infrastructure rollout	Evaluation of business models and consumer Willingness to Pay – **learnings from the Rapid Charging Network study** to be disseminated
Fragmented user experience	Currently public infrastructure is offered through many different commercial options	**Harmonisation of access, booking and payment systems;** outputs from recent demonstration projects (Green eMotion) or existing consortia (e.g. Gireve in France) include initiatives to harmonise ICT platforms through development and dissemination of standards led by eMI³ (eMobility ICT Interoperability Group)
Battery and charging technologies still improving	Infrastructure requirements are continually changing to support vehicle innovations (e.g. power rating, technology type)	**Future proofing infrastructure investment** is needed to attract new infrastructure operators and create a competitive market

Contents

Using 2015 diversity factors, future EV fleets could add c.28 GW peak demand in 2050 if no charging management solutions are in place

Domestic power demand (GW)

Highest EV uptake scenario



NOTE this graph is illustrative:

- It uses an upper limit for future EV demand: it assumes diversity factors as observed today (from limited data and while no smart/controlled charging is in place)
- No attempts to forecast the future (non EV) domestic demand profile have been made, but changes are likely with increased electrification

Smart charging has the potential to reduce the demand from EVs at peak time to 0 GW, by spreading the EV demand over time of low demand

Profiles represent **constructive superposition** of the observed **2015 domestic demand profile** with **rated EV charging demand profiles (domestic only)** for the total UK EV fleet.

Diversity factors: 25% (domestic charging)

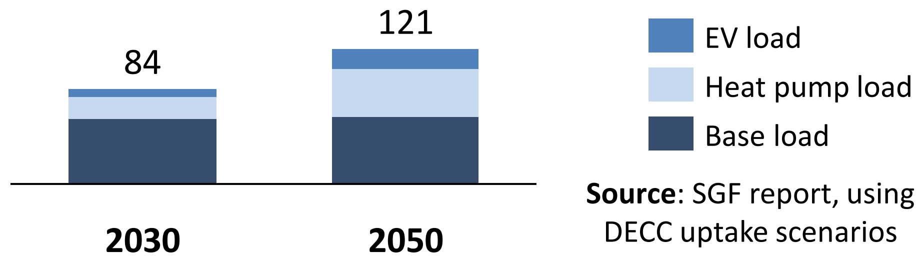
SOURCES: Element Energy analysis (2015), National Grid data explorer, EE for CCC (2013) “Infrastructure in a low-carbon energy system to 2030: Transmission and distribution”, Eurelectric (2015)

Studies have investigated the most cost effective grid reinforcement pathways to support large-scale uptake of low carbon technologies

Future mass deployed low carbon technologies

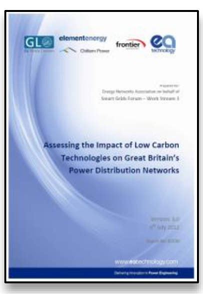
- Electric vehicles are only one of the low carbon technologies that will impact future networks
- Decarbonisation of heat through the use of **heat pumps** and further uptake of **distributed generation** all present challenges

Peak electricity demand forecast (GW)



Source: SGF report, using DECC uptake scenarios

Two studies consistent with the EV uptake scenarios used here have been reviewed



- Smart Grid Forum study from 2012
- Evaluation of investment needed in **distribution networks to 2050** and impact of 'smart' solutions

- CCC study from 2014
- Evaluation of investment needed in **transmission & distribution** networks to 2030 and **impact of rapid charging network**

DNO business planning requirements

- All technical and commercial investments made by a DNO must be defined in an 8 year business plans, validating how much cost DNOs can recover from DuOS charges[1]. The plan can however be reviewed in case of wide variations
- Current price period is RIIO ED1 (2015-2023), next one is RIIO ED2 (2023-31)

RIIO: Revenue = Incentives + Innovation + Outputs m EDM Electricity distribution

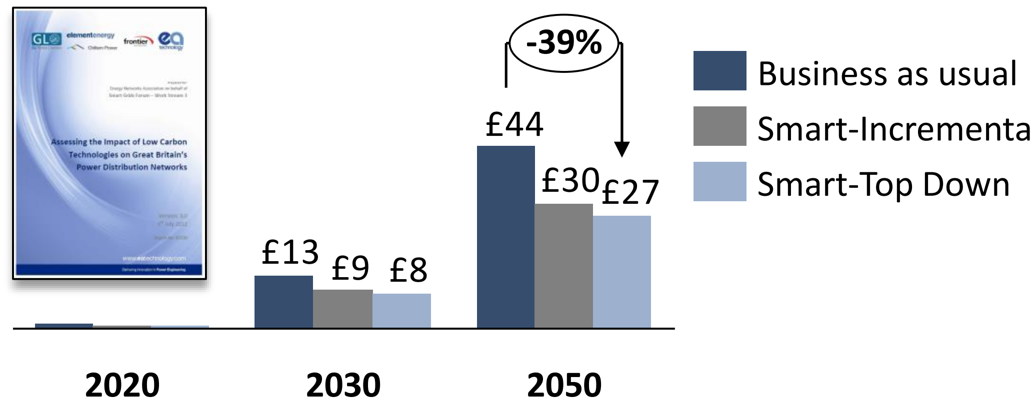
[1]DuOS charge= "Distribution use of system" charge (p/kWh)

The Smart Grid Forum study finds cumulative investment of £30-£44 billion by 2050 will be necessary, mostly after 2030

Smart Grid Forum (SGF) modelling

- SGF brings together key players from the electricity sector to consider technical, commercial and regulatory challenges concerning the transition to a low-carbon energy system
- In 2012, a study to understand grid reinforcement required to support uptake of low carbon technologies (most notably solar PV, heat pumps and electric vehicles)[1] quantified the level of investment needed for a business-as-usual approach and compared this with more innovative (or '*smart*') approaches to grid reinforcement
- Importantly, the report found that **smart technical and commercial solutions could yield up 30-40% savings** if used in conjunction with conventional reinforcement

Key output - gross cumulative investment required (£ billion)



Technical challenges pre-2030 are expected to be manageable within DNO business plans but significant investment will be required in later years

<u>Relevant sensitivities</u>

- **Increased CP power** – LV networks designed around residential ADMD.[2] TSB EV trial data identified >1kW of load per residential property (double current ADMD). Model sensitivity identified a further doubling of ADMD could require 50-65% increases in total investment required
- **Time clustering** – the cumulative investment required with a linear uptake of low carbon technologies is considerably lower

[1]EV uptake scenarios underpinning the SGF report are compatible with analogous scenarios used in the LowCVP transport fuels roadmap [2]ADMD = After diversity maximum demand

Recent studies predict only modest impacts to the electrical grid from the rollout of rapid public charging infrastructure

Committee on Climate Change

Scope: analysis modelled a scenario featuring key power sector decarbonisation targets[1] being met by 2030 with significant electrification using CCC's EV and heat pump uptake projections

Impact to transmission network to 2030

- "No climate action" scenario estimates c.£1bn investment needed by 2030
- "Core Decarbonisation" scenario estimates a **c.£19bn investment premium required for national transmission and interconnection system upgrades**
- Sensitivity for rollout of 5,000 rapid charging stations (6 x 50 kW CP per station) would only marginally increase peak power demand (c.2 GW)
- **Minor additional capacity required**

Impact to distribution network to 2030

- "No climate action" scenario estimates c.£25bn investment needed by 2030
- "Core Decarbonisation" scenario analysis identified a **c.£6bn investment premium for national distribution network upgrades by 2030**
- Sensitivity for rollout of 5,000 rapid charging stations would moderately increase investment requirements (c.£0.1bn) relative to central "Core Decarbonisation" scenario
- **Prioritise reinforcement of HV distribution networks**

Low carbon LONDON

Findings from Low Carbon London electric vehicle trials (2012-14) showed that c.16% of recharging events occurred at public infrastructure

Source: Committee on Climate Change "Infrastructure in a low-carbon energy system to 2030: transmission and distribution"

[1] *Core Decarbonisation* scenario: GHG emissions 60% below 1990 levels in 2030, power sector achieves c.50 gCO_2/kWh

A portfolio of conventional and 'smart' technical solutions are recommended for DNOs to reinforce distribution networks

Example impacts to the distribution network

Increased domestic ADMD

- Increased uptake of home charging services will increase domestic After Diversity Maximum Demand (ADMD), **directly impacting substation power capacity requirements**
- If EV uptake (albeit relatively low) is **clustered in localised areas**, it could cause **voltage and thermal capacity issues** on LV feeder cables and transformers and therefore require reinforcement
- Load management services will become increasingly important

Demand type evolution

- As energy efficiency gains are made in the system, demand from EVs (and from other low carbon technologies) will increase

Example solutions for the distribution network

Smart solutions[1]

- **Active Network Management (ANM)** systems can remotely manage loads and alleviate grid congestion by momentarily interrupting flow of charge to flexible demand (e.g. EVs) at peak times
- **Demand Side Response (DSR)** signals registered customers within the network to shift their load at certain times of day to alleviate voltage problems and thermal constraints
- **Local intelligent EV charging control** allows the DNO to allocate a fixed capacity to multiple EVs for the duration of a charging cycle

Regular solutions

- Split feeders will partition load from existing feeders onto new feeders – *minor works*
- New transformers enable voltage support and additional charging capacity – *minor works*
- Major works would involve greater investment where the minor modifications not sufficient

1- 'Smart' solutions are novel technical/commercial solutions that are more flexible and less disruptive to implement that conventional analogues. Many 'smart' systems are currently being trialled through the Low Carbon Network (LCN) Fund

Consumer engagement, regulatory amendment and new commercial frameworks are all key enablers to allow smart grid reinforcement

1. New commercial arrangements

- New DNO/customer and DNO/generator interactions must be contractually facilitated for demand and generator-side management to be effectively conducted
- Tariff options must accurately reflect the different levels of flexibility that customers/generators can shift demand/output and for how long
- Currently **DNOs are dependant on suppliers to adopt new Time of Use (ToU) tariffs** and pass them on to customers, but DNOs could provide ToU information to customers
- Payment systems must facilitate tariffs for customers and generators providing such services
- DNO interfaces with smart meter data to access consumer demand and network node data must also be designed

2. Flexible commercial frameworks

- The RIIO (Revenue = Incentives + Innovation + Outputs) framework aims to achieve long-term value for money for electricity customers whilst responding to market uncertainties
- Key enabler technologies (monitoring devices, communications links, control systems) could be **deployed early to minimise incremental instalment costs**
- A top-down approach to grid reinforcement is high risk; requiring high upfront capital investment but is expected to be more cost effective in the long-term
- DNOs and TSOs are collaborating to develop an **industry framework to share access to DSR resources**,[1] focussing initially on 'dispatchable' DSR (i.e. not static ToU)

3. Consumer engagement

- The aims and benefits of DSR should be clearly articulated to electricity customers
- Domestic customers may decide to participate based on competitive offerings
- Commercial customers may seek to modify certain practices to benefit to access lower cost electricity but will require confidence from DNOs that services offered are long-term

4. Other key enablers

- Land leasing arrangements
- Lead times on planning & deployments

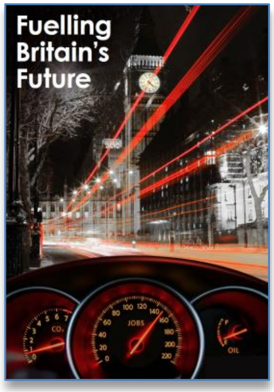
- **Top-down strategy**: upfront investment deployed in advance of need with further investment when network reaches headroom limit
- **Incremental strategy**: investment only occurs as and when networks reaches headroom limits. Enablers are deployed alongside the solution variants on an incremental basis.

Source: Smart Grid Forum (2014), [1]Electricity Network Association "Shared Services Framework"

Not only can the impact of plug-in vehicles on network be minimised but EVs could also deliver beneficial services to the grid

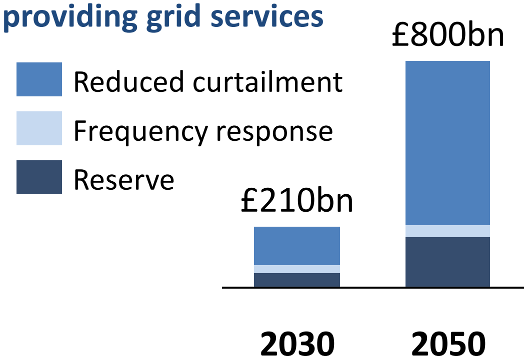
electricity

Identified synergies between plug-in vehicles and the grid[1]



- A fleet of c.23 million of EVs in the UK by 2050, could:
- Provide **response** (to maintain grid frequency over second/minute timescales), **reserve** (to manage supply/ demand imbalances over minute/hour timescales) and **reduce curtailment** of intermittent renewables
- Synergies could bring aggregated annual revenues of **£160 and £100/vehicle in 2030 and 2050** respectively

Annual revenues from EVs providing grid services



On-going studies on grid services EVs could deliver

- National Grid is currently investigating[2]: nationalgrid
    1. The potential for EVs, heat pumps and other **residential loads to provide frequency response to the grid**
    2. Enhanced frequency response and synthetic inertia from a range of distributed generation and demand sources to develop **new enhanced frequency response services** to become available in the future
    3. Opportunities for increasing response speed requirements to seek **'rapid primary frequency response reserve',** driven by network needs and new technology capabilities
    4. Ancillary service products for **aggregating portfolios of smaller loads** (e.g. STOR runway[3])
- Potential benefits of combining rapid CP stations with energy storage solutions in grid constrained areas is currently being investigated
- Several UK DNOs are currently studying the potential of Vehicle 2 Grid

[1]Cambridge Econometrics for ECF "Fuelling Britain's Future" (2015), [2]Public tender "Potential for frequency controlled electricity consumption from EVs and HPs", [3]STOR = Short Term Operating Response.

Summary of challenges – DNOs and TSOs will need information on EV location to plan investment accurately

electricity

Network challenges	Description	Example solution / enabler
Impact of charging power peaks on network	Domestic charging peak is expected to coincide with existing system peak demand, straining substation capacity	Significant **investment in conventional grid reinforcement and 'smart' technologies** (undiscounted, high estimate of £30-£45bn by 2050) Research needed to understand relative impact of 3kW vs 7kW charge point deployments (higher rates offer great flexibility for smart charging in theory)
Insufficient installed generation capacity	Increasing diversified peak power demand in domestic and commercial sectors could require new generation	Significant **interconnection and transfer capacity upgrades** requiring c. £20bn investment by 2030
Unreliable local EV forecasts	Accurate EV uptake is critical to DNO business planning; unreliability can present significant risk to the system. IEC code of practise that requires charge points installers to notify DNOs is mostly not followed by installers and/or DNOs don't have the procedure in place to receive the data	**Improve forecasting** (timing and location) of EV uptake and charging demand in network planning. ENA supporting on-going discussions between DNOs and government to release **EV uptake locations at a geographically disaggregated level.** Funding for charge points could be tied to the IEC code of practise that requires charge points installers to notify DNOs, DNOs to have dedicated procedure to receive and process the related data

Summary of challenges – DNOs and TSOs will need information on EV location to plan investment accurately

Network challenges	Description	Example solution / enabler
Capture EV synergies with the grid	EVs could help the integration of the intermittent renewable generation through timely charging or provide services, e.g. frequency regulation	Dynamic Time of Use tariffs; Aggregators entering the domestic market; National Grid and UKPN currently studying the case of frequency regulation (EV stock increase required before significant opportunities become available); R&D bodies investigating impacts of Vehicle-to-Grid services on vehicle batteries
Low uptake of demand response measures	DNOs are unable to influence customer behaviour through DuOS charges (only suppliers can offer ToU tariffs to customers and potential savings are low)	Develop a **tailored ToU tariff** to attract EV users, thereby increasing demand response stock and enabling collation of accurate EV uptake figures. **Incentivise energy suppliers to communicate ToU tariff benefits** to EV users. – *industry (suppliers, DNOs, aggregators) and Ofgem are working extensively on these topics, notably through the Smart Grid Forum*
Poor DNO / EV user interface	Currently no incentive for drivers to notify DNOs of newly acquired EVs	

Contents

Millions of charge points (mostly residential) will be needed to support widespread EV deployment, with uncertainty over charging technologies

Infrastructure roadmap

Charging infra-structure network

		2015	2020	2025	2030	2050
Public network	Total sites	*Many sites but variable offer*	**Visible and accessible network to all drivers** c. 500	**Full national coverage** c.1,100 *c. 10 charge points per site*	c.2,200	*Dependant on BEV/ PHEV split and charging rates*
	Cost		£20-40m	£130-230m	£300-530m	
	Technology	Rollout of primarily conductive rapid (40+kW) charging points in short term Future type and rates will depend on technology developments				
Residential	Cars/vans	3-7 kW off-street or shared on-street	300-370k	**Solutions to provide certainty of access to homes w/o off-street parking**	4-7 million	10-15 million
Depot / workplaces	Cars/vans	3/7/22 kW	8-10k		100-200k	400 -550k
	Buses and HGVs	>40 kW CP (plug and wireless) installed with concurrent trials of alternative power delivery systems		Potential rollout of alternative power delivery systems e.g. dynamic charging on highways, battery swap or overhead cables	4-5k	20-25k
Investment in electricity networks (transmission & distribution) – cumulative from 2015			**EV related DSR commercial arrangements formalised**	**Introduce smart systems alongside conventional network upgrades**	Up to c. £20bn for transmission and £30-45bn for distribution*	

**To handle decarbonisation of the grid and uptake of EVs, heat pumps and distributed generation such as PV panels*

Legend

Cost

Total CPs

Technical

Plug-in electric vehicles stock

Projections are based on policy-led uptake scenarios presented on page 25

Data supported quantification of infrastructure requirements

Thousand vehicles	2020	2025	2030	2050
Cars	300	1,500-2,500	4,000-8,000	20,000-25,000
Vans	60	250-400	700-1,300	3,400-4,000
HDVs	<5	10	20	130

Dashed lines represent high uncertainty

Major milestone /enabler

Cost estimates are cumulative costs from 2015
CP = Charge point

A visible, accessible and reliable public charging network should be rolled out for light vehicles

1 End user experience of public charge points

- Current public infrastructure is fragmented with several operators offering various access conditions and variable reported reliability
- Beyond the number of charge points, a network should meet some criteria to be useful to EV drivers:
  - Well marketed to drivers (e.g. clear signs, uniform signage across the country)
  - Easy to operate (e.g. multi socket connections, simple payment system, etc.)
  - Immediately accessible (e.g. PAYG, dynamic booking systems, live status information)

Recommendations

R&D / industry / LAs: Improve and build existing network and develop a national platform compatible with multiple vehicle types to remotely communicate with public infrastructure (e.g. dynamic booking, simple payment systems, availability notification) and consider joining cross platform projects (e.g. EMi[3]); embed criteria in relevant funding programs

2 Economics of public charge points

- The business case for public charge points remains challenging

Recommendations

Central gov.: Continue funding program and monitor progress, embed end user experience criteria in support programs

Local Authorities: support programs where local fleets can provide a base load to charge points that can also be accessible to the general public; facilitate exchange between relevant stakeholders (DNOs, end user, charge point operators) to help optimum siting; share best practise findings with other LAs

On-going trial programs: Share key learnings relevant to business case and end user experience (e.g. current Rapid Charging Network project)

Industry: DNOs could communicate areas of adequate network capacity to infrastructure developers to avoid high connection costs

Source: Element Energy

Solutions to facilitate overnight charging will be required across residential areas and depots

3 Residential areas

- Purchasing an EV requires certainty of access to charging, which is best provided by access to overnight home charging
- Ambitious uptake scenarios and unbalanced access to off street parking in urban/rural areas mean many households will need new solution for access to 'home charging'

Recommendations

Local Authorities: Continue (or begin) to investigate solutions to infrastructure for home owners without off-street parking and share findings; implement a tenants' right to install infrastructure for rented properties; support car club installation of charge points in dedicated bays; implement rules for new builds and retrofit to be 'socket ready' (successfully done in Westminster City Council)

R&D bodies & industry: develop identification systems for residential infrastructure shared between multiple users

4 Depots / workplaces and fleets

- Fleet operators of HDVs are likely to be faced with high local network reinforcement costs (already observed) – an investment in assets not own by the fleet operator: an unfamiliar risk and procedure

Recommendations

Local gov. : facilitate the interface between DNOs and fleet operators and prediction of 'demand cluster' for optimised investment; socialise early adopter case studies to share lessons learnt

Central gov. and regulator: align EV uptake ambition with network reinforcement needs to allow/encourage 'top-down' strategy (upfront investment in advance of need)

R&D bodies: support trial of new technologies (e.g. inductive, ultra fast conductive, 'automatic plug-in' etc.) that would be more practical for fleets than current technologies

Central Government: Continue to monitor private sector investment trends for residential and depot based infrastructure and adjust support as needed

Source: Element Energy

Mitigating the impact of electric vehicles on the network will require new technologies and new commercial arrangements

5 Impact on electricity network

- Without management of the charging time, EVs could (when added to other technologies such as heat pumps) require large investment in new distribution infrastructure (substations, cables) and possibly new generation / interconnection capacity. The Smart Grid Forum identified that ‘smart’ technical and commercial solutions could save in the order of £15bn on distribution network reinforcement costs by 2050
- DNOs will need information on EV location and uptake to plan investment and smart solutions rollout accurately
- Research is needed to understand relative impact of 3kW vs 7kW charge point deployments
- Although less studied benefits to the grid could also be available: as flexible loads, recharging EVs could provide important grid balancing services to maintain grid frequency, to manage supply and reduce renewable curtailment

Recommendations

Central Gov. & regulators: support DNOs to access geographically disaggregated EV uptake data;

Installers and DNOs: improve platform for compiling charge point installation notifications (as stipulated by IEC)

Regulators, electricity suppliers and DNOs: develop new commercial arrangements and tariffs required for the uptake of smart charging solutions and for customer engagement [Ofgem’s Low Carbon Fund already supports these activities]

On-going trial programs: disseminate findings on local network management solutions to DNOs and related stakeholders

R&D bodies & DNOs: Investigate network related topics: charging/demand management technologies, Vehicle-2-Grid, impact on battery life, co-locating energy storage devices with rapid charge points to alleviate strain on weak grid

Refer to the full report for more detail on smart solutions

Source for quoted costs: Smart Grid Forum, Assessing the Impact of Low Carbon Technologies on UK power distribution, 2012

Contents

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Acronyms

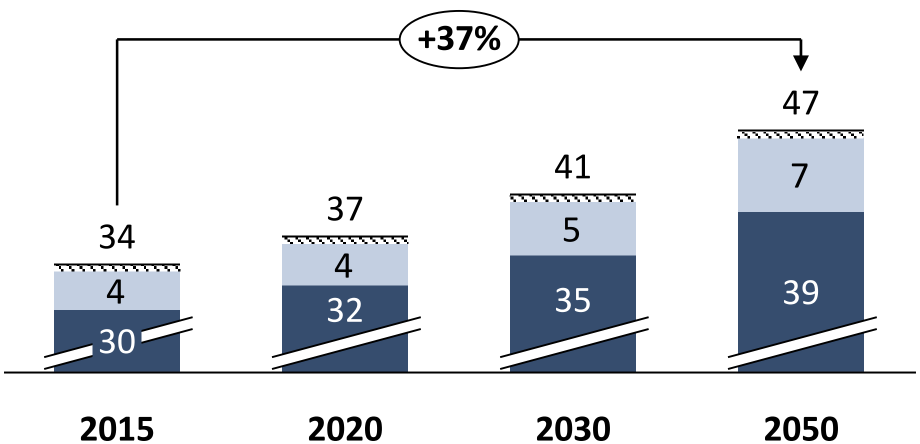
AC	Alternating Current
ADMD	After Diversity Maximum Demand
AFV	Alternative Fuel Vehicle
ANM	Active Network Management
BEV	Battery Electric Vehicle
BS	Battery Swap
CCC	Committee on Climate Change
CCS	Combined Charging System
CHP	Combined Heat and Power
COMAH	Control of Major Accident Hazard
CP	Charge Point
DC	Direct Current
DECC	Department of Energy & Climate Change
DfT	Department for Transport
DNO	Distribution Network Operators
DSR	Demand Side Response
DUKES	Digest of United Kingdom Energy Statistics
DuOS	Distribution use of system
EC	European Commission
EE	Element Energy
eMI3	eMobility ICT Interoperability Group
ETI	Energy Technologies Institute
EU	European Union
EV	Electric Vehicle
FLT	Fork Lift Truck
GW	Giga Watt (billion Watt)
HDV	Heavy Duty Vehicle (bus, HGV)
HEV	Hybrid vehicle
HGV	Heavy Goods Vehicle
HSE	Health and Safety Executive
HV	High Voltage
ICE	Internal Combustion Engine
IEC	International Electro-technical Commission
LCL	Low Carbon London
LCN	Low Carbon Network
LV	Low Voltage
NG	National Grid
OEM	Original Equipment Manufacturer
OLEV	Office for Low Emission Vehicles
PAYG	Pay As You Go
PHEV	Plug-in Hybrid Electric Vehicle
PiP	Plug-in Places
PM	Particulate Matter
R&D	Research and Development
RED	Renewable Energy Directive
REEV	Ranger Extender Electric Vehicle
RIIO	Revenue = Incentives + Innovation + Outputs
SGF	Smart Grid Forum

Acronyms

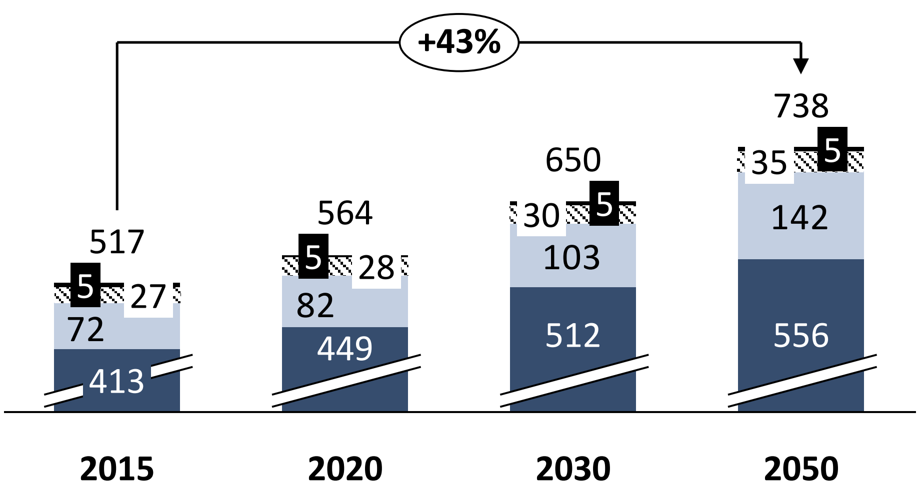
STOR	Short Term Operating Response
TEN-T	Trans-European Transport Networks
ToU	Time of Use
TSB	Technology Strategy Board
TSO	Transmission system operator
TTW	Tank-to-Wheel
ULEV	Ultra-Low Emissions Vehicle
WTT	Well-to-Tank
WTW	Well-to-Wheel

The modelling of the future UK fleet is based on DfT traffic and park size projections

Total UK vehicle stock (million vehicles)



Total vehicle km travelled (billion km)



- Future vehicle projections use figures provided by DfT:
  - Cars stock to increase from c. 30 million to 39 million and c. 550 billion vehicle km travelled by 2050
  - Vans stock to increase from c. 3.5million to 7 million by 2050
  - HGVs stock to increase from c. 500 thousands today to c. 630 thousand by 2050
  - Buses stock and vehicle km travelled to stay broadly constant at around 170 thousand units and 5 billion vehicle km travelled
- Overall fleet and km increase of c. 40% between 2015 and 2050

Buses HGVs Vans Cars

Source: DfT Road transport forecasts (available online) as well as direct supply of National Travel Model outputs for the case of cars

The powertrain/fuel uptake scenarios underpinning the Infrastructure Roadmap are policy led

Uptake scenarios focus on alternative fuels

- **The scenarios used are not intended to cover all possible outcomes but instead focus on cases with ambitious uptake of alternative fuels**
- Scenarios are **policy led,** typically based on targets set by the Committee on Climate Change (sources shown next); they are illustrative rather than based on detailed of new modelling technology costs and customer decision making behaviour
- Therefore the uptake scenarios represent possible futures where low and ultra low emission powertrains are successfully deployed
- Focus is intended to provide the most interesting inputs for the analysis of the Infrastructure Roadmap – e.g. a ‘business as usual’ case where petrol and diesel continue to provide over 98% of road transport energy would not require new refuelling/recharging infrastructure
- In accordance with the Fuel Roadmap, blends higher than B7 are not considered for the mainstream fuels and E20 is considered only from the 2030s
- Scenarios have enabled future infrastructure requirements to be quantified and upfront costs capital costs for public infrastructure have been estimated. Cost of setting new fuel production assets, distribution/logistics costs and general infrastructure operating costs have not been considered. Costs of other incentives that might be required to achieve the uptake scenarios (e.g. vehicle grants) haven not been estimated in this study

Overview of the powertrain options considered and key sources

	Cars and vans	Buses	HGVs	NRMM
RELEVANT POWERTRAINS /FUELS	▪ ICE: petrol, diesel, LPG, (gas), (H_2 in early years) ▪ EVs: Battery EVs, plug-in hybrid EVs, fuel cell (FCEVs)	▪ ICE: diesel, (bio)methane ▪ EVs: BEV, PH/RE, FCEV ▪ (Liquid air for cooling/hybrid power)	▪ ICE: diesel, (bio)methane, (methanol) ▪ EVs - in lighter segments only	▪ ICE: diesel, LPG, (gas), Liquid air for refrigeration units ▪ (Batteries and Fuel Cells – in some applications)
KEY SOURCES / INDICATORS	▪ The Carbon Plan and the Committee on Climate Change's recommendations ▪ H_2Mobility Phase 1 report, 2013 ▪ Historic trends for petrol/diesel split	▪ Current and announced commercial availability, policy drivers ▪ *Alternative Powertrain for Urban buses*, 2012 ▪ CCC – 4th Carbon Budget Review	▪ Current and announced commercial availability ▪ DfT HGV Task Force ▪ TSB-DfT Low Carbon Truck Trial ▪ CCC – 4th Carbon Budget Review	▪ *Data on fuel usage of NRMM is sparse* ▪ *More qualitative approach suggested*

Parentheses indicates the powertrain/fuel option is expected to stay niche in the 2050 horizon

HGV = Heavy Goods Vehicles, NRMM = Non Road Mobile Machinery

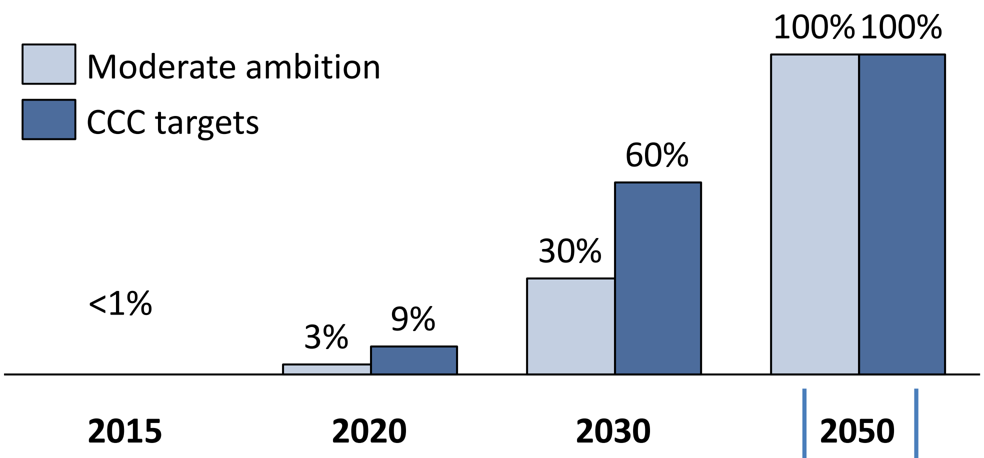
Cars and vans are expected to transition to zero emission powertrains for the UK to meet its GHG reduction targets

- Cars and light commercial vehicles ('vans') are treated together as they have the same technology options and fall under the same electrification targets in the Carbon Plan.
- Sales of vans running on **methane** are not considered in the modelling on the basis of the low commercial availability (only 2 models on the market), lack of policy drivers for growth and aforementioned electrification targets. Any gas demand resulting from vans would be small enough to be considered negligible, in comparison to the potential gas demand from trucks.
- **Dual fuel vans running on diesel and hydrogen and Range Extender Fuel Cell electric vans** (being deployed currently in the UK and in continental Europe) are not modelled explicitly. Instead, their hydrogen demand is accounted for in the 'FCEV' heading. The specific requirements for dual fuel and range-extender H_2 vans are however considered in the Infrastructure Roadmap (e.g. dispensing pressure).

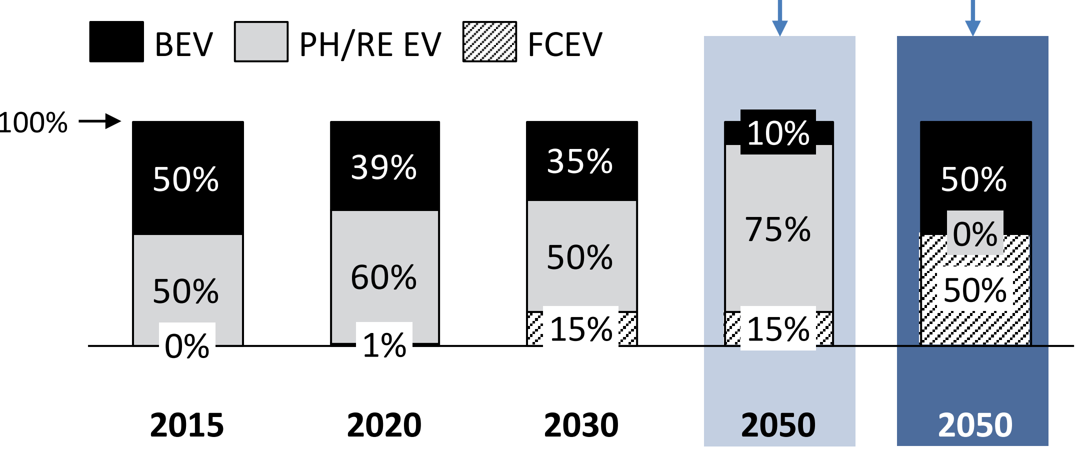
Source: Element Energy

We studied infrastructure requirements set by the Committee on Climate Change targets as well as a case with a slower EV uptake

Market share of EVs (new sales)



Breakdown of market share of EVs



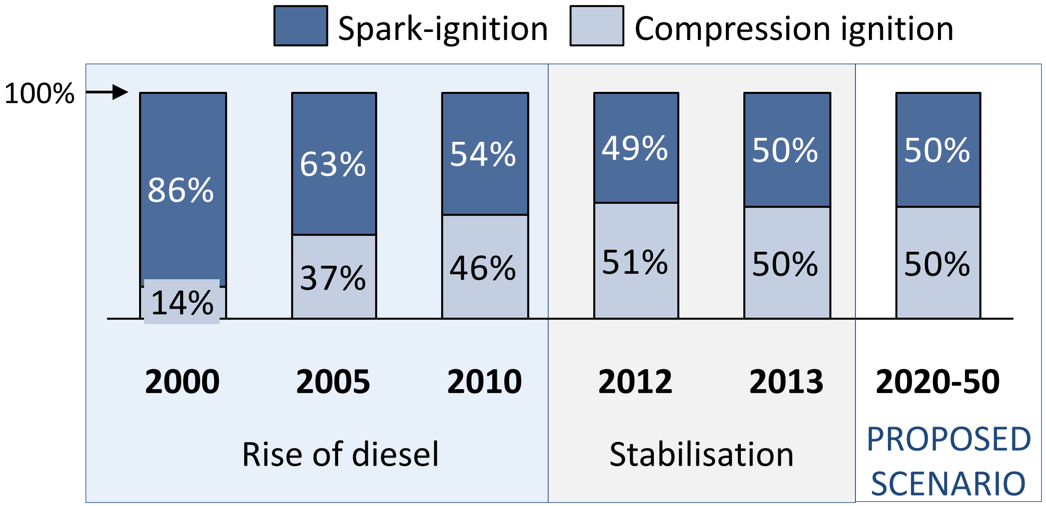
Scenarios

- Two EV uptake scenarios have been used:
  - ‘**CCC targets**’: EVs reach 60% market share by 2030 and Zero Emission vehicles reach 100% of market share before 2050
  - ‘**Moderate ambition**’: the 2030 CCC targets are not met but EV uptake is nonetheless high (30% new sales); by 2050 EVs represent 100% of sales but are mainly PHEVs or RE-EVs, i.e. still reliant on liquid fuels

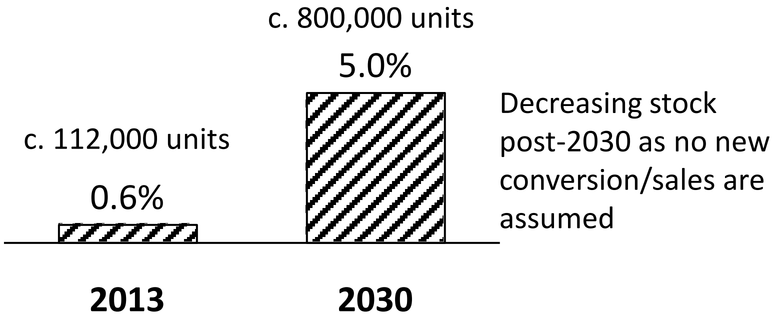
Sources: Element Energy, UK H_2Mobility report Phase 1 (2013), *Pathways to high penetration of EVs*, EE for the CCC (2013), *Options and recommendations to meet the RED transport target*, EE for LowCVP (2014)

We assumed continuation of the observed petrol /diesel share for cars and modelled an ambitious LPG uptake

Sales of new cars with Internal Combustion Engine vehicles - split between spark-ignition ('petrol' type) and compression ignition engines ('diesel' type)



Share of spark-ignition cars (ICE and HEV) stock that run on LPG



Scenarios

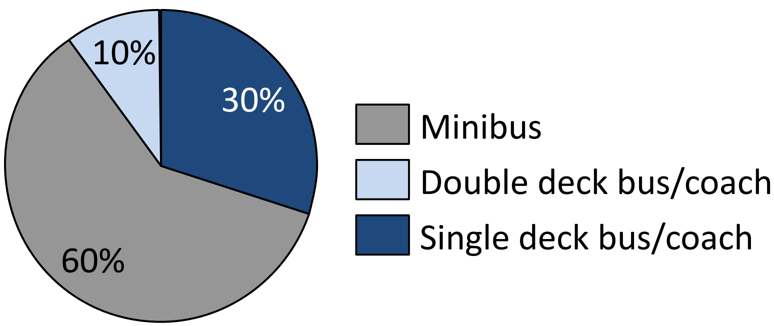
- We assumed that the current split of petrol/diesel engines for new cars (50/50) is maintained going forward
- In line with the Fuels Roadmap, diesel will be B7 (EN590) with an increasing amount of drop-in renewable diesel – i.e. no compatibility issue to be considered for the distribution infrastructure
- For petrol engines, we will evaluate the amount of:
  - Ethanol needed if the E10 becomes the main grade by 2020 and E20 by 2032
  - LPG needed for a case where the rate of conversion (or sales if OEM supply is put in place) accelerates to reach 5% of the petrol car stock (equivalent to c. 40,000 conversions per year until 2030)
- All new vans are assumed to run on diesel

Sources: Element Energy, SMMT data for 2000-2013 sales, UKLPG for LPG 2013 figures

Buses have many powertrain options but overall small fuel use so we used only one scenario, where all technologies see high sales

Current UK bus market

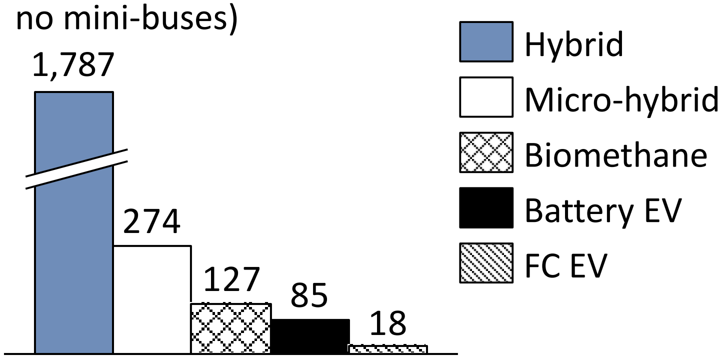
UK bus fleet, c. 165,000 vehicles:



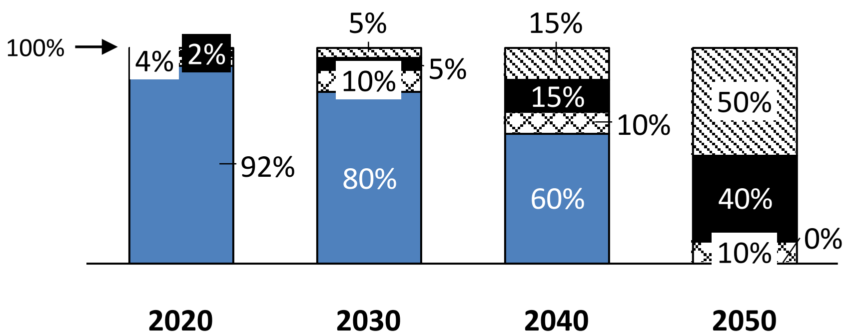
Scenario

- We ramped up the alternative fuel market share from 2030, in line with the European study[1] that suggests that the TCO of battery and FC e-city buses will become comparable and competitive with diesel and CNG buses by 2030[1]
- We assume 90% uptake for Zero Emission Vehicles by 2050
- This is lower that the 100% FCEVs assumed in the CCC projections, to reflect the fact that double decker buses (and buses in highly rural areas) might require gas

UK low emission buses (all single or double deck, no mini-buses)



New buses sales scenario:



'Diesel' refers to a blend of B7 and drop-in renewable diesel, as per the Fuels Roadmap

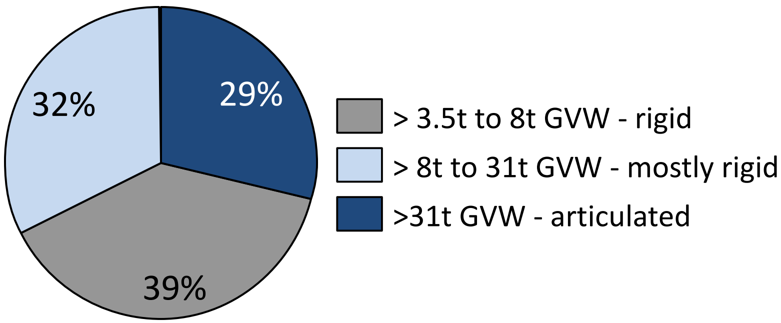
FCEV (Bio)methane
BEV Diesel, includes hybrid

Source: Element Energy, DfT Statistics Table VEH0601, LowCVP Low Carbon Emission Bus Market Monitoring (Jan 2015), CCC, 4th *Carbon budget*, 2013 1 - Alternative Powertrain for Urban buses study (2012)

For Heavy Goods Vehicles, we tested a high uptake of both electric (battery and fuel cell) and gas trucks

Current UK Heavy Goods Vehicle market

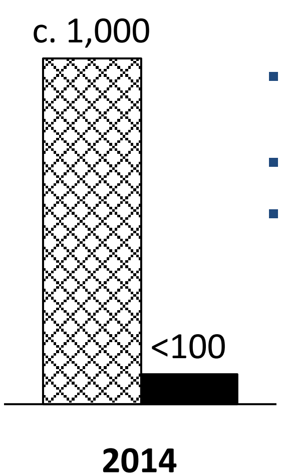
UK HGV fleet, c. 460,000 vehicles:



Scenario

- We to modelled a High Alternative Fuel Uptake case where both pure electric and gas trucks reach a significant sales levels in their respective markets (light and heavy trucks)
- FCEVs also capture a large share of the market, as per the CCC's vision of the role of hydrogen

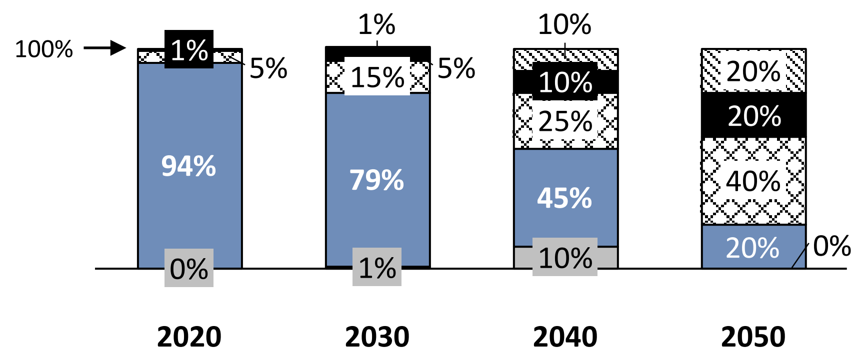
UK low emission trucks - estimates



- *Gas trucks all over 18t GVW, mostly dual fuel (diesel and methane)*
- *Electric trucks all under 18t GVW*
- *FCEV light trucks at early demo stage*

Methane
Battery EV

New truck sales scenario:

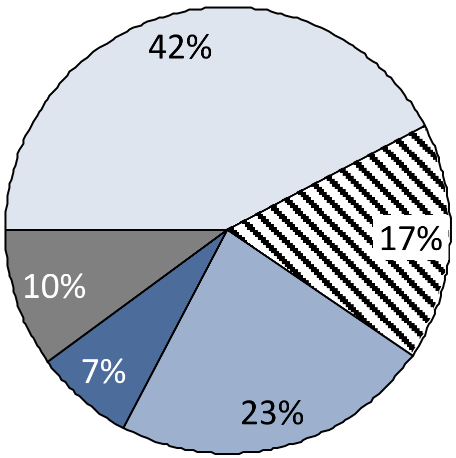


'Diesel' refers to a blend of B7 and drop-in renewable diesel, as per the Fuels Roadmap

FCEV
BEV
Methane
Diesel, includes hybrid
Diesel LPG dual fuel

Non-Road Mobile Machinery typically refuels in private depots/premises but the case of LPG, liquid air and hydrogen were considered

UK NRMM fleet for industry, construction and agriculture, c. 700,000 units in 2014:



Scenario

- We to considered (qualitatively, considering the lack of disaggregated data on fuel use) the infrastructure impacts of:
  - A transition to Liquid Air for HGV refrigeration units
  - An increase in LPG, battery and hydrogen use for forklifts

Beyond the blending of renewable drop-in diesel in diesel, options for cleaner fuels are:

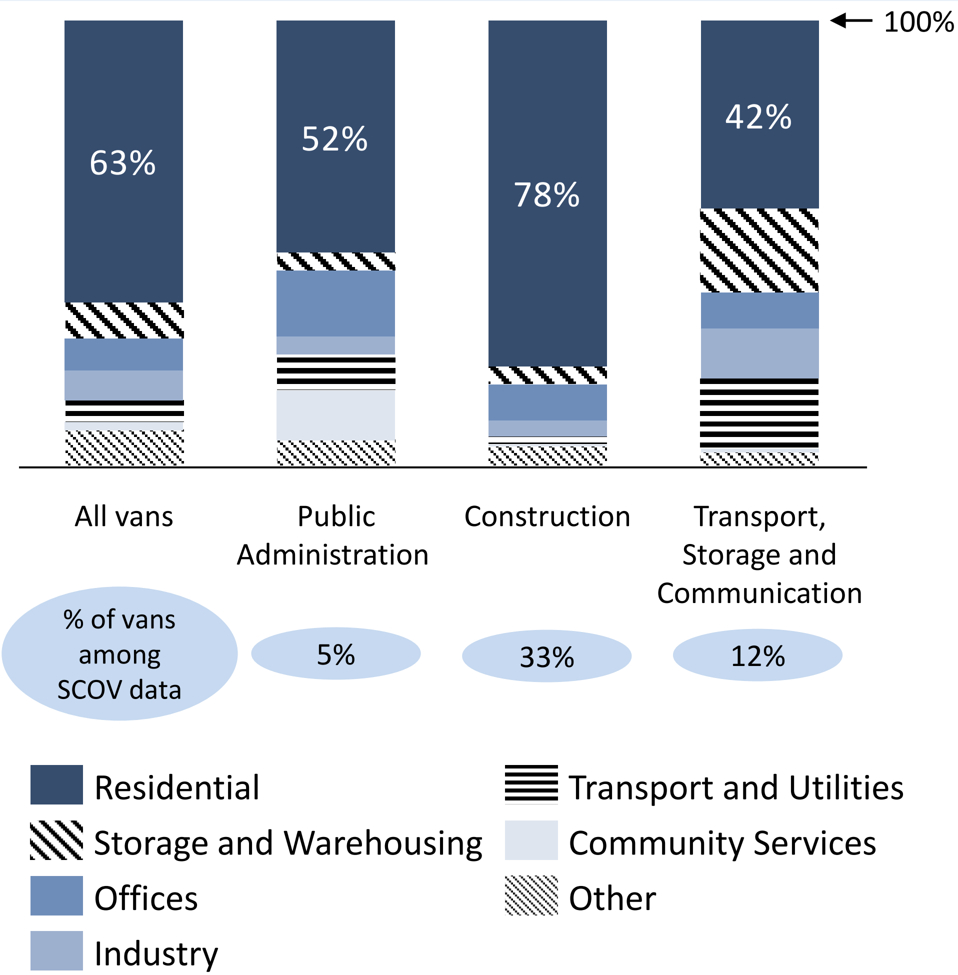
- Agricultural tractors → (Limited options, possibly (bio)methane or high blend biodiesel)
- Portable generator sets → (Could transition to LPG, Battery and Fuel Cell packs for some uses)
- Other off-roads → (LPG, limited alternative fuel options)
- Refrigeration units on HGVs → LPG, could transition to Liquid Air
- Forklifts → Use of LPG (already used by c. 30% of forklifts) and batteries could increase, could transition to hydrogen

Other off-roads: Telescopic Handlers, Backhoe Loaders, Excavators, Cranes, Bulldozers, Compressors etc.

Source: Element Energy analysis based, on DfT statistics requested in Jan 2015 and *Non-Road Mobile Machinery Usage, Life and Correction Factors* AEA for Dt (2004) , industry input for LPG use in forklift

Appendix – overnight location of light commercial vehicles

End location of last trip of the day



- Travel survey data suggests that over 60% of vans are parked at residential premises overnight
- Interview data confirms this is the case for many of the UK's largest fleets, such as courier companies, utilities etc.
- This has implications for provision of charging for electric vans, since many fleets would require home rather than workplace charging
- Daytime workplace charging is often not possible since vans are travelling or parking at multiple locations during the working day
- Fleet interviews suggest that this has practical implications, such as reimbursing employees' electricity costs, recovering charging equipment from employees leaving the company etc.

Source: Element Energy analysis of Survey of Company-Owned Vans (SCOV)

Appendix – Charge point terminology: connector types

Common terminology and connector types

<u>Common Terminology</u>

'Slow' charge: single-phase 3kW AC charging. In most cases, uses Mode 2 in conjunction with BS1363 or Type 1 connector

'Fast' charge: typically single- or three-phase 20kW to 25kW AC charging, also include 7kW. In most cases, uses Mode 3 in conjunction with Type 1 or Type 2 connector (see on the right).

'Rapid' or 'Quick' charge: either three-phase 40kW+ AC (Mode 3/ Type 2 connector), or more commonly 50kW DC (Mode 4/ JARI DC or Combo connector – see right).

<u>Connector Types</u>

BS1363 (3-pin): While limited to single-phase charging with a maximum current of 16A (13A in UK) and voltage of 250V, a domestic 3-pin socket can be used for Modes 1 and 2 charging.

Type 1 (Yazaki): SAE J1772 connector and plug can only be used for single-phase charging applications. International standard IEC 62196 Type 1 specification permits 250V at 32A or 80A.

Type 2 (Mennekes): Allows both single and three-phase charging, and includes two data pins for a full 'handshake'. The Mennekes plug has a single size and layout for voltages up to 500V and currents from 16A single-phase up to 63A three-phase.

European standard for AC

JARI DC (CHAdeMO): The CHAdeMO standard allows a high-voltage (up to 500VDC) high-current (125A) 'rapid' or 'quick' charging via a JARI DC connector, the standard connector used in Japan. And the most common DC connector used in UK.

Combo Coupler: SAE is developing a 'combo' (combined) variant of the Type 1 (US) or Type 2 (EU) connector with additional pins to accommodate DC charging at 200-450 Volts up to 90 kW.

European standard for DC

Appendix – Charge point terminology: charging modes

Charging modes

Mode 1: single or three-phase AC, with a maximum permitted current of 16A. The supply voltage is up to a maximum of 250V for single-phase or 480V for three-phase. As no residual current device (RCD) is included in the equipment, Mode 1 is not recommended for public or commercial use.

Mode 2: single or three-phase AC supply, with a maximum permitted current of 32A. The supply voltage is up to a maximum of 250V for single-phase or 480V for three-phase supply. Mode 2 includes the **use of an Residual Current Device located within the cable**.

Mode 3: single or three-phase AC supply, with a maximum permitted current of 32A. The supply voltage is up to a maximum of 250V for single-phase or 480V for three-phase supply. As Mode 3 includes **data connection**, Mode 3 enables full vehicle isolation and 'smart' charging capability.

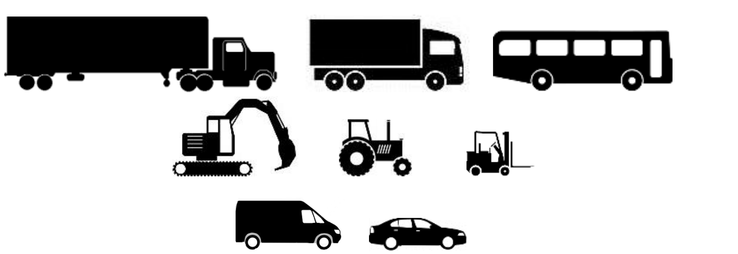
Mode 4: incorporate an 'off-board' charge point and provide a DC supply at the socket. The DC supply has a maximum permitted current of 1000VDC (typically 500VDC) and current of up to 400A (usually 125A). Mode 4 **includes a full 'handshake' so enabling 'smart' charging capability**.

Source: Element Energy and Ecolane, 2013

Appendix – There are broadly two types of refuelling infrastructure for liquid fuels in the UK

Refuelling at private depots: c.25% fuel sales

- Large fleet operators including public transport operators, hauliers, logistics companies, forklift operators tend to operate designated refuelling depots suited to their ‘return to base’ operations
- Such facilities tend to be private and exclusively service a single vehicle type
- **Most buses and heavy good vehicles refuel in depots** – share of diesel supplied through depot:
  - 90% for buses, 40% for coaches
  - 80% articulated trucks, 45% rigid trucks



Refuelling at public forecourts: c.75% fuel sales

- Generally, public vehicle refuelling (passenger cars, vans, motorbikes, scooters) is facilitated by one of the UK’s c.8,600 forecourts
- Refuelling forecourts are publically accessible and are generally owned and operated by large oil companies (e.g. Shell, BP, Esso, etc.), independent retailers and supermarket chains

Appendix – National Grid "Future energy scenarios"

National Grid has developed four scenarios for future electricity generation and gas supply sources to 2050

Affordability
More money available

Affordability
Less money available

Low Carbon Life (LCL) is a world of high affordability and low sustainability. More money is available due to higher economic growth and society has more disposable income. There is short term volatility regarding energy policy and no additional targets are introduced. Government policy is focused on the long term with consensus around decarbonisation, which is delivered through purchasing power and macro policy.

Gone Green (GG) is a world of high affordability and high sustainability. The economy is growing, with strong policy and regulation and new environmental targets, all of which are met on time. Sustainability is not restrained by financial limitations as more money is available at both an investment level for energy infrastructure and at a domestic level via disposable income.

No Progression (NP) is a world of low affordability and low sustainability. There is slow economic recovery in this scenario, meaning less money is available at both a government and consumer level. There is less emphasis on policy and regulation which remains the same as today, and no new targets are introduced. Financial pressures result in political volatility, and government policy that is focused on short term affordability measures.

Slow Progression (SP) is a world of low affordability and high sustainability. Less money is available compared to Gone Green, but with similar strong focus on policy and regulation and new targets. Economic recovery is slower, resulting in some uncertainty, and financial constraints lead to difficult political decisions. Although there is political will and market intervention, slower economic recovery delays delivery against environmental targets.

Sustainability
Less emphasis

Sustainability
More emphasis

Appendix – TEN-T Core Network