UK-Saudi Electric Vehicles Enhanced Education and Research Network

Industry Outlook on EV Charging Forecourts

This report is presented to Dr Mohamed Darwish of Brunel University as part of the Industrial consultancy for the British Council Project with King Abdulaziz University in Kingdom of Saudi Arabia on "*UK-Saudi Electric Vehicles Enhanced Education and Research Network*".

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Table of Contents

Introduction

As the adoption of battery electric vehicles (BEVs/EVs) in all sectors both public and private continues to grow, the future of EV charging forecourts serving long-distance travel and transportation will become increasingly important. The goal for these charging forecourts is to provide convenient and reliable charging options for drivers of diverse EV types traveling long distances, to distribute and oftentimes generate energy in an efficient and sustainable manner, to help reduce range anxiety and make EVs a more practical option for these types of trips, and overall to enable electrification of the road transport industry across all applications.

Trends

Ultra-Fast Charging

One trend that is expected to shape the future of these charging forecourts is the development of ultra-fast charging technology, allowing EVs to charge their batteries much faster than is currently possible thereby reducing the amount of time drivers need to spend at charging stations. As the average capacity of EV batteries increases, both due to higher range capability of personal vehicles and increased electrification of freight and mass transport fleets, charging speeds are trending towards higher power levels to meet increased capacity demand as well as dwell time demand. With the advent of ultra-fast charging, it will become possible for drivers and passengers to quickly charge their vehicles while taking already mandatory and necessary breaks during long trips, making it more practical to travel longer distances in an EV.

Distributed Energy Sources

Another trend that will shape the future of long-distance EV charging forecourts is the continued growth of both distributed grid-sourced renewable energy such as offshore wind, hydropower, and solar PV farms, as well as locally generated microgrid renewables such as building-mounted solar PV, and devoted onshore wind and industrial-scale PV farms. As the use of renewable energy generation increases, charging forecourts will increasingly be powered by clean, green energy, making it possible for drivers to charge their vehicles with a reduced carbon footprint. The sourcing of this generation is also in development, with the rise of power purchase agreements (PPAs) directly from renewable energy generators as well as renewable-specific power aggregators offering clean energy from diverse sources in a contracted package. For cases in which generation cannot be sourced from the grid, such as highly isolated forecourt installations, continued development in microgrids and downstream (local) generation is opening the possibility of operating high-power charging infrastructure entirely independent of the electrical grid.

Multiple Charging Technologies

A further technological trend enabling more universal and more operable EV charging forecourts is the proliferation of more practical mechanisms for providing charge to the increasingly diverse mixture of EV types. Traditional EV charging mechanisms include differing types of wired protocols and plugs, all taking the form of cables which are manually carried and plugged in by the driver or user of the charging station. Beyond issues around reliability, mechanical failure and inconvenience, traditional cabled charging means become increasingly problematic as charging powers augment. Essentially, the more powerful the charge, the thicker the cable and the larger the plug. Further, the potential hazard of handling increases greatly with both higher power and higher utilization (more users manipulating the charging cables with higher frequency yields greater wear & tear, resulting in possible exposure of bare conductors to weather and humans, and significant damage to machines, vehicles, or people). Current and future solutions for these myriad issues include pantograph charging, wireless charging, and robotically automated charging. Pantograph charging is a solution primarily meant for HGVs (heavy goods vehicles, including buses and coaches) whereby an armature foundation automatically descends upon the roof power assembly of an aligned vehicle to provide power at high voltage/current. Wireless charging is a technology suitable for all vehicle types in which power is transferred over an airgap via magnetic induction, enabling convenient, contact free and autonomous charging. Robotically automated charging is a complex and costly methodology including robotic arms and various assemblages autonomously plugging in traditional cables or pantographs.

Conveniently located charging facilities

To serve long-distance travel and transportation, charging forecourts will need to be strategically located along major highways and transportation routes. Locations of charging forecourt infrastructure will also need to consider availability of energy – either adequate power supply from the electrical grid, or availability of sources for generation such as solar or wind. Logically planned forecourt locations will make it easier for drivers to find charging stations and form predictable routes around those dependable charging sites, and will help to reduce the time they spend searching for charging points and planning for unnecessary contingencies.

The importance of the charging experience

In addition to the physical location of these charging forecourts, the user experience both in interfacing with charging equipment and refreshing themselves will also be important. The future of long-distance EV charging forecourts is likely to feature user-friendly interfaces, diverse payment options, and mobile apps that provide real-time information about charging station availability and wait times. Payment mechanisms in present forecourts as well as future forecourts will need to be diverse and catered to provide accessibility to all types of users on the road – including but not limited to contactless bank & credit cards, mobile application based payments, possibility to pay cash in partnered retail or service facilities, and possibly even cryptocurrency payment options. These features will make it easier for drivers to plan their trips and find charging stations when they need them.

Importance of safety and reliability

Furthermore, a vital component of user experience is safety and facilities reliability. Users of EV charging equipment need to be able to charge without fear of personal injury from machinery, environmental factors, or abuse or neglect from other people. Safety around equipment and electricity primarily comes down to regular maintenance and machine reliability – forecourt staff should be present to regularly check, test, and maintain all machinery users interface with as well as all upstream supply equipment. Safety around environmental factors also comes down to proper maintenance by forecourt staff, as well as intelligent design of both charging facilities and any jointed retail or leisure facilities. Safety around other forecourt users and the general public must be considered in terms of safety from crime and vandalism, as well as safety from traffic and belligerent drivers – this should be enforced by traffic management and safety personnel employed by the charging forecourt.

Dwell time will dictate services

In terms of refreshment for drivers and users, intelligent planning, operation, and maintenance of accessible facilities both retail and concessionary/complimentary provides both the functional user experience necessary for charging forecourt utilization as well as the revenue generation necessary for sustaining the forecourt and attracting both users/consumers and businesses to operate within or in partnership with the forecourt. These facilities presently include all of those to be expected at a standard forecourt (also referred to as rest-stops or highway services) such as restrooms, options for food and coffee, and some grounds for walking or exercising of pets.

Furthermore, one will find at present EV charging forecourts amenities corresponding to higher dwell times than standard forecourts – meaning amenities which generally appeal to users spending longer amounts of time and thus having further consumption than the standard traveller stopping at a traditional forecourt. These amenities can include meeting rooms and workspaces, gyms and exercise equipment, barista-made coffee and tea, grocery shopping and retail, post offices, EV leasing showrooms and advising staff, play areas for children, and even showers. Future charging forecourts will need to further cater to this increased average dwell time and utilization, in addition to demonstrated facility demands of resources such as rest-stops and transportation truck service stations. These facilities further servicing and utilizing long dwell-times in future charging forecourts may include expanded retail opportunities resembling shopping malls, restaurants and more formal dining options, full-scale gymnasiums and co-working facilities, parks and outdoor grounds, hotel and privacy options, and perhaps even amusement parks and hobby activities.

Business models encompassing charging forecourt offerings and opportunities presently are being structured in various more-or-less experimental fashions, but as EV demand increases and charging forecourt demand grows, development of business models to effectively and profitably provide infrastructure and amenities will become ever more important. In the charging forecourts of today, retail amenities such as cafés, post offices and grocery shopping are typically operated by retail-specific entities independent from the owner and operator of the charging forecourt itself, with site level oversight and management being the responsibility of either the owner/operator of the forecourt, or an additional service and maintenance specific entity. The charging forecourt of the future will need to operate under similar models but on a much larger scale with finer refinement of operating models to create a highly reliable offering with available opportunities for margin to attract the best possible operators of functional facilities, retail amenities, and mechanisms to transition ever further drivers in to electric vehicles.

Impact of smart charging

Another important factor that will shape the future of long-distance EV charging forecourts is the development of smart charging systems. These systems will use algorithms to optimize charging times, manage demand, and prevent grid overloading. This type of technology will make charging more efficient, reduce wait times, maintain reliability of charging infrastructure, and help to ensure that charging forecourts are able to keep up with growing demand.

In conclusion, the future of EV charging forecourts serving long-distance travel and transportation is likely to be shaped by a combination of factors, including the growth of renewable energy sources, the development of new charging technologies, the strategic location of charging stations, the user experience, and the implementation of smart charging systems. These trends will help to make long-distance travel in an EV more convenient, reliable, and sustainable, and will play a key role in the continued growth of the EV market across all sectors.

Current State of EV Charging Forecourts

Industry Overview

The present nascent state of the EV Charging Forecourt industry is being led by a select few developers and operators within primarily UK and European geographies. Initial proliferation of charging forecourts within these geographies has occurred due to a primary selection of factors, including high and growing utilization of EVs by diverse driver types, availability of (lower) cost renewables-sourced energy, government subsidy and legislative support, relatively compressed.

Although public charging infrastructure is in a far more mature stage, and exists throughout all geographies in which EVs have a presence, the goal of this analysis is to evaluate EV charging specific en-route forecourts. Public charging infrastructure and the operational models driving it is analysed as a reference point to charging forecourts, given the close relation in technology, business models, and utilization trends. The upcoming section "Review of Charging Networks" provides some data and trends on that state of industry, and the upcoming sections on "UK Government Definitions" provide a baseline of government consideration for growing demand on charging infrastructure.

Furthermore, the utilization and uptake of EVs is essentially directly correlative to the demand for charging infrastructure and more specifically for en-route charging forecourts, thus available electric vehicles and their relevant performance metrics (battery, range, charging capabilities, capacities, price, etc) are tabulated and analysed in the upcoming sections on "Current EV Makes". The driving technologies enabling effective provision of charging forecourts at present are considered in brief in the following Technology section, as well as the capital and business model schemas driving development and deployment of that technology. Related are the amenities and retail opportunities providing nourishing user experience as well as more classical revenues for operational entities.

The following table gives an overview of the current EV charging forecourt operators, their serviced geographies, operational models, and schemas for sourcing energy:

Developer	*Geographies*	*Operational Model*	*Energy Sourcing*
Gridserve	UK	Retail Partner	Direct Generation/PPA
Shell	UK, NL & FR (EU)	Direct Management	Direct Generation/PPA
MFG	UK	Direct Management	PPA

A 'Retail Partner' operational model is defined as the user facilities being operated and managed by a devoted retailing entity, without direct management by the developer and charging systems operator of the forecourt.

A 'Direct Management' operational model is defined as the user facilities being directly managed by the developer/charging operator of the forecourt, with participating retail partners operating within the managed facility.

A 'Direct Generation/PPA' energy sourcing model is defined as sourcing energy both from owned generation assets and from the electrical grid: from on-site generational sources (such as solar PV and grid energy storage), from owned & operated off-site generational sources (such as devoted solar PV or wind farms), and via power purchase agreements (PPAs) with both aggregators and/or generators. A 'PPA' energy sourcing model, following on, is energy supply via a PPA (there are various types of PPAs, of course).

As an example, some European Renewable Energy Generators offering direct PPAs are: Statkraft, Lightsource BP, EDF Group, Eneco, Ørsted.

And some Energy Aggregators in the UK are: Bulb, Octopus, and OVO Energy.

The following table of definitions covers some of the abbreviations used throughout this study – terms for relevant technologies, vehicles, energies, and commercials:

Abbreviation	*Full Text*	*Definition*
EV	Electric Vehicle	A battery electric vehicle. Also referred to as "BEV".
PHEV	Plugin Hybrid Electric Vehicle ("serial hybrid")	A hybrid electric vehicle with a battery that can be recharged just as an EV, but still does has engine. In most modern PHEVs, the petrol engine does not directly power the drivetrain, but instead generates charge for the battery mated to the electric drivetrain.
HGV	Heavy Goods Vehicle	A large vehicle such as a semi lorry or a bus.
MDV	Medium Duty Vehicle	A large vehicle such as a panel truck.
LDV	Light Duty Vehicle	A mid-sized vehicle such as a commercial van.
EVSE	Electric Vehicle Supply Equipment	A device providing electric power to an EV, thus recharging said vehicles' batteries.
DCFC "DC"	DC Fast Charger	A rapid or ultra-rapid (by UK definitions) charger providing DC power directly to the battery of an EV.
L2, or "AC"	Level 2	Level 2 EV charging is AC "fast" charging.
CCS	Combined Charging System	A plug type combining AC charge input and DC charge input – CCS2 in Europe, CCS1 in the USA.
CHAdeMO	Japanese organisation	A DC charging protocol and plug type, international.
Pantograph	Pantograph	A roof mounted, automatic charging apparatus.
OBC	Onboard Charger	A power electronics modules in EVs converting AC power from external sources to DC power to charge the EV battery.
WPT	Wireless Power Transfer	Transfer of power over an airgap using induction.

Static " "	Static WPT	Wireless charging of a non-moving vehicle.
Dynamic " "	Dynamic WPT	Wireless charging of a vehicle in motion.
kW	kiloWatt	A measure of energy – 1000 watts.
kWh	kiloWatt-hour	Energy usage – 1000's of Watts used per hour.
SoC	State of Charge	% charge of an EVs battery at a given time.
PV ("Solar")	Photovoltaics	Solar energy generating panels.
PPA	Power Purchase Agreement	A long term contract between an electricity generator and a customer (In this report, a renewables generator and a CPO).
TSO	Transmission System Operator	Entity responsible for transporting energy (electricity) from generators (power plants, wind, etc) to either DNOs or directly to large-scale consumers.
DNO	Distribution Network Operator	Operator of electric power distribution system delivering electricity from the national transmission network (grid) to most end users.
Supplier	Energy Supplier; Aggregator	An entity receiving energy from a DNO(s) and selling that electricity contractually to consumers.
CPO	Charge Point Operator	An entity installing & maintaining charging stations, can either own & operate, or operate for 3rd parties.
MSP	Mobility Service Provider	An entity offering EV charging services to EV drivers. They provide access within their own network, and/or via other networks via eRoaming (access agreements).
OEM	Original Equipment Manufacturer	A producer of non-aftermarket equipment and components – in this case, EVSEs (chargepoints) & EVs.
Public Charging	Public Charging Infrastructure	Charging infrastructure within the public space servicing any qualified EV user (in case of memberships etc).
Dwell Time	" "	The amount of time spent at a particular facility/place.
CapEx	Capital Expenditure	A cost of providing the non-consumable parts of a system.
OpEx	Operating Expense	An ongoing cost for running an asset.
V2G	Vehicle to Grid	Technology enabling energy to be pushed back to the grid from the battery of an EV. Bi-directional energy flow between an EV and the power supply network.
V1G	Smart Charging	Technology to control the time and magnitude of charging power from the power source to the EV. Used for management of power supply and capacity, such as frequency regulation and congestion management.
ICE	Internal Combustion Engine	[Vehicle driven by] a heat engine in which combustion of a fuel occurs, providing energy to drive the vehicle.

FCEV	Fuel Cell Electric Vehicle	Electric vehicle using a hydrogen fuel cell, typically in combination with a battery (just like a BEV), for power.

Major Issues

EV charging infrastructure in the public realm in general, and EV charging forecourts specifically, is faced throughout proliferation with a host of issues both technological and human behavioural in nature. Technological barriers creating issues in implementation and sustainability can block growth and usability greatly, but fortunately technology can always be improved to cater to our rapidly changing transportation and energy sectors. Human behaviour and education, though, is often the most difficult element of new infrastructures to adapt. Consistent efforts must continue to be made by governments, industry, and individuals in order to enable our electrification. Below several examples of common issues in charging forecourts and public charging infrastructure are presented:

Vandalism & Improper Use

As is common in the design of public-space street furniture, so should be for charging infrastructure – accessible components are subject to defacement and breakage:

Figure 1: A vandalized DCFC

Figure 2: The abandoned CCS2 plug of a DCFC

Utilization & Scarcity

As demand for charging infrastructure increases along with growing EV adoption, access for all to limited DCFCs within in-transit routes is becoming more crowded. Rollout of in-transit charging must match growing demand in order to facilitate electrification of transport.

Figure 3: Queues at a Tesla Supercharger. Source : Forecourt Trader / Jamie Waters

Figure 4: A bp pulse dual DCFC waits to be installed at an already crowded and power constrained forecourt.

Infrastructure Installation & Cost

Industry capabilities for installation of charging infrastructure face a significant learning curve in terms of complexity and cost of charging stations, especially as power levels grow and new technologies are introduced ever faster. Available sites, which may suffer from accessibility and available space issues as well as issues with availability of power, can be difficult to work with when demand for power and space intensive infrastructure requires fitting of services for which said site was not designed. Blockers of installations herein can include availability of qualified installation technicians & engineers, availability of power and the connection to said power from the local TSO / DNO (electrical grid), and availability of financing and capital options to fund expensive equipment and labour.

Review of Charging Networks: Pricing & Business Models

EV charging networks available to EV drivers of all different categories must maintain market competitiveness as well as availability metrics to sponsor utilization by the public balanced with business sustainability of the operating enterprises. Presently, CPO & MSP industries are working out through direct experience how to operate between governments, land owners/developers and utility operators on one side, and consumers and vehicle fleet operators on the other side, to provide highly functional and sustainable charging forecourt infrastructure.

Government: Definitions, Regulation & Legislation

Government plays a vital role in development of charging forecourts – in terms of providing favourable & functional legislation for forecourt operation and development, providing regulation of relevant industries such as energy suppliers, EV OEMs, electrical +

charging equipment OEMs, facility/retail operators, CPOs & MSPs, and providing definitions and leadership for directing electrification for all across all industries.

UK Government EV Charging Definitions

Charging Device Type	*Charging Speed / Power*	*Power Supply / Charger Type*
Slow Charging Devices	3kW to 6kW	1PH AC
Fast Charging Devices	7kW to 22kW	3PH AC
Rapid Charging Devices	25kW to 100kW	DC / DCFC
Ultra Rapid Charging Devices	100kW+	DC / DCFC

The UK defines charging infrastructure primarily by power level – meaning the power at which the equipment can charge an EV. The above table does an approximate matching of those type definitions to the actual power sources behind the charging devices, and the types of devices applicable to each type of category.

UK Government ChargePoint Location Categories

ChargePoint Location Name	*ChargePoint Location Description*
On Street	Charging devices located on residential streets.
En-route	Charging located to continue a journey, in places such as motorway service areas, service stations, electric forecourts, hotels, etc.
Destination	Charging located at the end of an EV journey or where a driver may typically stop for an extended period of time. Places such as retail car parks, leisure, educated areas, and mass transport.
Forecourt	Charging located specifically at EV charging forecourts.

The UK defines charging infrastructure locations (which the UK refers to as "ChargePoints") by the type of service they offer – service to residents without off-street parking ("on street"), service to motorway travellers ("en-route"), and service to travellers at end of journey ("destination"). The "forecourt" service/location is not strictly a UK government definition, but rather a common way of designating "en-route" chargepoints aggregated in a specific service location.

The following charging networks overview considers the providers of some current charging networks, the types of network locations provided, the business models those networks operate under, the UK categories of the chargepoints, and the cost per unit energy (kWh) in sterling.

Current Charging Networks - Prices and Business Models

Network	*Regions*	*Location Types*	*Business Model*	*Charge Speed (as per UK definitions)*	*Cost per kWh (in GBP £)*
Gridserve	UK	Forecourts, En-route	Owned Assets (CPO)	Fast	0.49/kWh
				Rapid	0.62/kWh
				Ultra-Rapid	0.64/kWh
Shell Recharge	UK / EU	Forecourts, En-route	Owned Assets (CPO)	Rapid	0.79/kWh
				Ultra-Rapid	0.85/kWh
MFG EVPower	UK	Forecourts, En-route	Owned Assets (CPO)	Rapid / Ultra-Rapid	0.79/kWh
BP Pulse	UK	En-route	CPO, Subscription	Fast, Subscription	7.85/Month + 0.44/kWh
				Rapid, Subscription	7.85/Month + 0.55/kWh
				Ultra-Rapid, Subscription	7.85/Month + 0.65/kWh
				Fast, Open	0.57/kWh
				Rapid, Open	0.69/kWh
				Ultra-Rapid, Open	0.79/kWh
Fastned	EU	En-route	CPO, Subscription	Rapid + Ultra-Rapid, Subscription	10.56/Month + 0.44/kWh
				Rapid + Ultra-Rapid, Open	0.63/kWh
IONITY	EU	En-route / Destination	CPO (no MSP)	Fast	0.43/kWh + MSP Margins
				Rapid + Ultra-Rapid	0.70/kWh + MSP Margins
Tesla	EU	En-route / Destination	CPO, Owned Assets	Ultra-Rapid	0.37-.46/kWh
Electrify America	USA	En-route	CPO, Subscription	Rapid + Ultra-Rapid, Subscription	3.31/Month + 0.26/kWh
				Rapid + Ultra-Rapid, Open	0.36/kWh
EVgo	USA	En-route / Destination	CPO, Subscription	Fast + Rapid, Subscription	5.78/Month + 0.24-0.33/kWh
				Fast + Rapid, Open	0.32-0.45

Legend

Parameter	*Data*	*Definition*
Business Model	Owned Assets (CPO)	The entity "Network" operates both the chargepoints as well as developing and

		operating the sites on which those chargepoints are installed. This may be in cooperation with one or several retail/service partners.
	CPO, Subscription	A chargepoint operator who has a significant subscription model in their business / valuation.
	CPO (no MSP)	A chargepoint operator who operates on behalf of 3rd party entities, with MSP companies providing the direct transactional interface with customers (EV drivers).
	CPO, Owned Assets	A chargepoint operator primarily servicing only its' own customer base: Tesla DCFCs are restricted (at least classically) to only to Tesla drivers.
Cost per kWh	/Month versus /kWh	Per month costs are billed to subscribers of plans with preferential per kWh rates (per kWh of energy consumed while charging from network EVSEs).
	MSP Margins	Margins from the customer-facing MSP added to the costs charged by the CPO.

The above table is not intended to be an exhaustive list, but instead demonstrative of the major public charging infrastructure operators of en-route services within the UK, EU (Western/Central Europe), and USA. Below are a few summative points of analysis:

- Cost per kWh is, on average, far lower from owned asset networks and networks servicing exclusively their own customers/fleet vehicles.
- Cost per kWh is essentially correlative to regional electricity prices; this is why 1. Network prices are divided geographically (US networks trend cheaper than EU networks, which trend cheaper than UK networks) and 2. Networks using electricity generated and/or distributed by their own assets can offer lower pricing than those fully reliant upon PPAs from electricity suppliers/aggregators (for example, Gridserve sources a good portion of their charging forecourt electricity demand from solar PV generation owned & operated by themselves and from onsite battery storage allowing for low-price off-peak purchasing from the grid, whereas Shell sources energy directly via PPAs and does not benefit from the pricing benefits or arbitrage provided by onsite battery storage.). More on energy sourcing and battery storage in the following sections: "Review of Forecourt Business Models" and "Review of Onsite Energy Generation & Storage, Technology".

- Typically, only Rapid and Ultra-Rapid charge speeds are acceptable for forecourts and other en-route charging offerings – fast and lower charging are more appropriate for destination and home charging.
- Subscription models for access to networks only benefit frequent customers – so, an EV driver who often charges during journeys is economically motivated to subscribe.

Figure 5: AC (Level 2) Fast Charging at a Gridserve Forecourt. A contactless bank/credit card can be used to charge.

Figure 6: Rapid + Ultra-Rapid Charging Spaces at a Gridserve Forecourt, with overhead Solar PV.

Figure 7: Tesla Superchargers at a Gridserve Forecourt.

Review of EVs & Charging: Types, Manufacturers, Utilization & Duty Cycles

Electrification of the transportation sector can be seen across many vehicle types and all industries – what follows is a review of some of the EVs of various types available now, primarily focussed on the rapidly growing EV markets in the UK, EU, and USA. Following each review section of a particular vehicle segment will be a few analysis points of the associated duty cycles and charging cases. None of these tables are exhaustive, but instead cover selections of some average and some interesting vehicles relevant to this study. Battery capacity is given in total energy storage allowance (expressed in kWh), and charging capability is given in all available methods: AC charging for Level 2 infrastructure, DC (or DCFC) for rapid/ultra-rapid DCFC infrastructure, and pantograph overhead depot charging (for buses).

Current EV Makes: Buses

Manufacturer	*Model*	*Type*	*Passenger Capacity*	*Battery Capacity*	*Range (miles)*	*Charging Capability*
BYD	Enviro400EV	Transit	87 people	339kWh	160	2 x 40kW AC, 112kW DCFC, 300kW Pantograph
	K9	Transit	60 people	391kWh	250	80Kw AC, 150kW DCFC
Proterra	ZX5 35Ft	Transit	70 people	492kWh	160-240	221kW DCFC, 370kW Pantograph
Yutong/Pelican	E12	Transit	71 people	364kWh	200	300kW DCFC
Yutong/Pelican	TCe12 Coach	Touring	50 people	350kWh	250+	120kW DCFC
Volvo	7900 E	Transit	95	470kWh	200+	150kW DCFC, 300kW Pantograph
Wright	Electroliner	Transit	96	454kWh	200	150kW DCFC, 360kW Pantograph
Thomas/Proterra	C2 Jouley	School	81	226kWh	135	19.2kW AC, 90kW DCFC

Figure 8: City Bus charging on a 450kW Pantograph in Copenhagen, Denmark

- Buses meant for inner-city transit typically have a lower passenger to available battery ratio – meaning they are intended for maximizing the transportation of quantities of people over shorter distances. Touring buses need longer range between charging sites, and must have provision for passenger comfort.
- The advantage point of transit buses comes from access to fast charging methods, meaning;

    - Transit buses on frequent routes have limited dwell time between journeys, thus
        - Pantographs are the preferred charging method, being high power and with automatic interfaces not requiring direct driver intervention.
        - Transit bus battery sizes may decrease over time, given increased access to high power, low interference charging network reduces the necessity for vehicle range.
- Transit buses are not currently typical users of forecourts, but the Touring category of long-distances buses can presently be found using en-route and forecourt charging infrastructure, and as infrastructure density and EV technology continues to improve this utilization will augment.

Current EV Makes: Passenger Cars

Manufacturer	*Model*	*Type*	*Price ($-$$$)*	*Passenger Capacity*	*Battery Capacity (kWh)*	*Range (miles)*	*Charging Capability*
LEVC	TX	Hire PHEV	$$	5	31	80.6 EV 377 PH	AC 11-22kW DC 50kW
Clipper/LEVC	TX4	Hire BEV	$	5	40	150	AC 7kW DC 50kW
Daimler (Smart)	EQ	City BEV	$	2	16.7	60	AC 22kW
MG	MG4	BEV	$	5	61.7	225	AC 11kW DC 135kW
Nissan	Leaf	BEV	$	5	39	145	AC 6.6kW DC 46kW
Renault	Zoe	BEV	$	4	52	190	AC 22kW (43) DC 46kW
Mazda	MX-30	City BEV	$	4	30	105	AC 6.6kW DC 50kW
Fiat	500e	City BEV	$	2+	37.3	145	AC 11kW DC 85kW
Vauxhall	Corsa-e	BEV	$	4	45	175	AC 11kW DC 101kW
Citroen	eBerlingo	BEV Van	$	5+	45	125	AC 6.4kW DC 101kW
Hyundai	Kona	BEV	$	4	39.2	155	AC 11kW DC 44kW
Citroen	SpaceTourer	BEV Van	$	5+	45	110	AC 7.4kW DC 101kW
Kia	Nero	BEV	$	5	64.8	235	AC 11kW

							DC 80kW
Honda	Advance	City BEV	$	4	28.5	105	AC 6.6kW DC 46kW
Volkswagen	ID3	BEV	$$	4	58	215	AC 11kW DC 124kW
Tesla	Model 3	BEV	$$	4	57.5	235	AC 11kW DC 170kW
Hyundai	IONIQ 5	BEV	$$	5	54	185	AC 11kW DC 175kW
Polestar	2	BEV	$$	5	67	240	AC 11kW DC 136kW
Toyota	bZ4X	BEV	$$	5	64	205	AC 6.6kW DC 147kW
Nissan	Ariya	BEV	$$	5	63	200	AC 7.4kW DC 130kW
Peugeot	e-Traveller	BEV Van	$$	7	45	110	AC 7.4kW DC 101kW
Audi	Q4 e-tron	BEV	$$	5	76.6	250	AC 11kW DC 135kW
Volkswagen	ID5	BEV	$$	5	77	265	AC 11kW DC 135kW
Ford	Mustang Mach-E	BEV	$$	5	70	220	AC 11kW DC 109kW
Volvo	XC40	BEV	$$	5	78	235	AC 11kW DC 205kW
BMW	iX1	BEV	$$	5	64.7	220	AC 11kW DC 130kW
Volkswagen	ID Buzz	BEV Van	$$	5+	77	205	AC 11kW DC 175kW
Mercedes	eVito Tourer	BEV Van	$$	9	90	190	AC 11kW DC 110kW
Porsche	Taycan	BEV	$$$	4	83.7	295	AC 11kW DC 268kW
Mercedes	EQS	BEV	$$$	5	107.8	395	AC 11kW DC 207kW
Zero Motorcycles	ZF17.3	BEV Moto	$	1	17.3	142	AC 6.6kW
Harley-Davidson	LiveWire	BEV Moto	$	1	15.5	146	AC 3kW DC 25kW
Triumph	TE-1	BEV Moto	$$	1	15	100	DC 50kW

Legend

Parameter	*Data*	*Definition*
Price	$	20k – 40k (£, $, or €)
	$$	40k - 75k
	$$$	75k+
Type	BEV	Battery Electric Vehicle (pure)
	BEV Van	Electric Van (pure)
	Hire PHEV	A plug-in hybrid electric vehicle (having an engine & an electric drivetrain), used for hire (taxi).
	Hire BEV	A pure electric vehicle used for hire (taxi).
	City BEV	A pure electric vehicle designed specifically for use within and close around a city / town.

Figure 9: LEVC TX Taxi charging at a 350kW (capable) DCFC at a Shell Forecourt

Figure 10: A Nissan Leaf driver plugging in to an Enel X JuiceBox L2 EVSE. Source: Enel X

- EVs with sub-150 mile range (mostly City BEVs in above table) are not likely users of charging forecourts on transit routes, as the majority of their journeys take place within cities.
- Electric vans and other larger vehicles (pickup trucks also given, in following "LDVs" section) are just now becoming available given improving battery technology. These larger vehicle offerings are becoming more prevalent with better charging networks and EV technology.
- Electric motorcycles are a niche segment but as range and fast charging improves, increasingly these EVs are being used as long-distance cruising motos.
- Currently in more expensive EV models, and historically in newer EV models with improved aerodynamic and drivetrain technology, efficiency (miles of range per kWh of energy used) is getting better. The result of this is longer range with equivalent battery capacity.

- Evident in more expensive EV models above, charging speed capability is trending towards higher power – particularly with DC charging, the most used in en-route charging scenarios. This is partially due to growing battery capacity requiring more total power delivery, and partially due to better distributed charging infrastructure enabling longer journeys with consistent charge service.
- Ideal EV range seems to be arriving within 200 – 350 miles, as evident by averages in newer EV models being introduced. This can be seen as a confluence point between 1. Ideal EV battery cost versus range, 2. Range necessity and driver duty cycles, and 3. Available charging speeds. These 3 points are nuanced:
    1. As battery technology improves, an equilibrium is being attained – the optimum cost of sufficient battery capacity to enable optimal range of a vehicle. This optimal equilibrium point is of course different for vehicles of varying power requirements (motorcycles versus passenger cars versus trucks), and furthermore may change according to range requirements (geographies with longer distances to cover may require vehicles with more battery range). Overall, as EV battery cost lowers, it is becoming financially feasible to provide sufficient battery capacity for sufficient driving range in a market competitive EV.
    2. Drivers, on average, do not cover anywhere near the distance of an ideal EV battery range in a single day. On the exception days when they do, distance covered in a single session typically does not exceed the idealized range of 200 – 350 miles. The off-cycle duty of a rest stop is the target duration for recharging a useful portion of the EV battery, so a journey can be continued after.
    3. Improvements in chargepoint technology make servicing this off-cycle duty (the "rest stop" time period in which a driver on a journey stops to rest and refresh) more and more optimal. Charging speed and intelligence of energy consumption enable effective provision of power for time management during EV journeys.
- V2G Capability: As will be covered further in the "Future of Technologies" section, V2G is an important technology in enabling the adoption of electrification. Of the vehicles listed in the above table, only the Nissan Leaf is presently V2G capable, with the Volkswagen ID5 and ID Buzz being enabled for V2G within the year (2023). The Ford F-150 Lightning (in below LDV table) is also V2G capable.

Current EV Makes: HGVs (Trucks)

Manufacturer	*Model*	*Type*	*Payload*	*Battery Capacity*	*Range (miles)*	*Charging Capability*
Scania	Electric	Tractor	64t GTW	624kWh	218	375kW DCFC
Freightliner	eCascadia	Tractor	40t GCW	550kWh	250	260kW DCFC
BYD	T9	Tractor	36t	350kWh	125	150kW DCFC
Lion Electric	Lion8	Tractor	~60t	630kWh	221	300kW DCFC
Mercedes	eActros	Tractor	17.7t	336kWh	190	160kW DCFC
Peterbilt	220EV	Tractor	18t	282kWh	200	19.2kW AC 150kW DCFC
Kenworth	T680E	Tractor	45t	396kWh	150	150kW DCFC
Volvo	FH Electric	Tractor	44t GCW	540kWh	186	43kW AC, 250kW DCFC
	FL Electric	Rigid	16t	300kWh	190	22kW AC, 150kW DCFC
eMoss	EMS18	Rigid	18t	240kWh	155	22kW AC, 44kW DCFC
Freightliner	eM2 106	MDV	12t	325kWh	230	260kW DCFC
Mitsubishi	eCanter	MDV	7.5t	82.8kWh	75	22kW AC, 100kW DCFC
BYD	T7	MDV	11t	175kWh	125	150kW DCFC
DAF	LF	MDV	11.7t	282kWh	174	150kW DCFC
Mercedes	eECONIC	Trash	17.8t	336kWh	93	160kW DCFC

Legend

Parameter	*Data*	*Definition*
Type	Tractor	A heavy-duty vehicle, made to tow freight trailers.
	Rigid (truck)	A truck consisting of a tractor and trailer fixed together.
	Trash	A truck for hauling trash in a city or municipality.
Payload	N/A	The towing capability of given vehicle, if a Tractor. Or, if a Rigid or MDV or etc, the carrying capacity.

- Many HGVs (Trucks) currently offered do not have provision for AC charging, but rather only DC charging. The logic behind this:
    1. Many HGV batteries are so large that AC charging would not provide sufficient replenishment relative to capacity – for example, a 64t Scania Tractor with a 624kWh battery at near-0% SOC would only replenish 46 miles of range even after 12 hours of charging on a standard 11kW AC charger (132kWh of energy charged).

    2. An onboard charger (OBC) is required to convert inputted AC electricity into DC to supply to the battery. OBCs are subject to inefficiency in converting the inputted AC (10+%, on average), and furthermore represent a significant hardware cost (5+% of EV cost) – if the provision of an OBC can be avoided by exclusively charging via DC direct to the EV battery, it is the economic solution in terms of both CapEx and OpEx.
    3. Many HGVs are currently designed primarily to charge at depots which they return to predictably or travel between.
    4. The above reasonings are range limiting, of course, and are charging to adapt to superior in-transit charging infrastructure thus providing increased HGV range.

- Some MDV truck models, as well as specialized models such as Trash lorries and Construction vehicles, are designed for very different applications than long-distance haulage oriented Tractor semi-trucks.
    1. HGVs designed for Trash collection have predictable routes within concentrated localities, thus do not need to have much range capability. Batteries, being a principal expense in EVs, should be specified only as much as necessary. This makes Trash vehicles an unlikely fit for forecourt charging.
    2. HGVs designed for haulage primarily within construction and industrial sites have low range requirement, but high power utilization (massive loads and difficult terrain) – this equates perhaps to large battery capacities, but low range. This makes construction-site vehicles an unlikely fit for forecourt charging.

Current EV Makes: LDVs (Parcel Vans, Last Mile, Service Vans)

Manufacturer	*Model*	*Customer Types*	*Payload*	*Battery Capacity*	*Range (miles)*	*Charging Capability*
Stellantis	Peugeot e-Expert	Trade/Fleet	6.6cbm/1275kg	75kWh	205	11kW AC, 100kW DC
	Vauxhall Vivaro-e	Trade/Fleet	" "	" "	" "	" "
	Citroen eDispatch	Trade/Fleet	" "	" "	" "	" "
	Toyota Proace	Trade/Fleet	" "	" "	" "	" "
	Peugeot ePartner	Trade/Fleet	3.3cbm	50kWh	170	11kW AC, 100kW DC
	Vauxhall Comboe	Trade/Fleet	" "	" "	" "	" "
	Citroen eBerlingo	Trade/Fleet	" "	" "	" "	" "
	Toyota Proace C	Trade/Fleet	" "	" "	" "	" "
	Fiat E-Ducato	Trade/Fleet	17cbm/1900kg	79kWh	224	22kW AC
	Renault Master E	Trade/Fleet	13cbm/1420kg	52kWh	126	22kW AC

	Peugeot e-Boxer	Trade/Fleet	8cbm/1070kg	62kWh	169	22kw AC, 50kW DC
	Vauxhall Movano	Trade/Fleet	17cbm/2100kg	70kWh	139	22kW AC 50kW DC
	Citroen e-Relay	Trade/Fleet	17cbm/2100kg	70kWh	139	22kW AC 50kW DC
Maxus	eDeliver 3	Trade/Fleet	6.3cbm/945kg	52.5kWh	151	7kW AC, 90kW DC
	eDeliver 9	Trade/Fleet	9.7cbm/1200kg	88.55kWh	219	22kW AC, 100kW DC
Ford	E-Transit	Trade/Fleet	15.1cbm/1758kg	68kWh	196	11kW AC, 115kW DC
Mercedes	eSprinter	Trade/Fleet	11cbm	55kWh	93	7.4kW AC, 50kW DC
	eVito	Trade/Fleet	6.6cbm	41kWh	92	7.2kW AC
Volkswagen	ABT eTransporter	Trade/Fleet	6.7cbm/996kg	37kWh	82	7.2kW AC, 50kW DC
Iveco	eDaily	Trade/Fleet	18cbm/1273kg	74kWh	186	22kW AC, 80kW DC
Rivian	R1T	Private/Trade/ Fleet	Pickup	135kWh	328	11.5kW AC, 220kW DC
Ford	F-150 Lightning	Private/Trade/ Fleet	Pickup	131kWh	320	19.2kW AC, 150kW DC
GMC	Hummer	Private	Pickup	212.7kWh	329	19.2kW AC, 350kW DC

Legend

Parameter	***Data***	***Definition***
Customer Types	Trade/Fleet	A vehicle commonly operated by independent tradesmen (e.g. plumbers, electricians, handymen, etc small businesses), or by larger fleet operators such as delivery companies, utilities, service companies, etc.
	Private/Trade/Fleet	A vehicle operated by individuals for primarily non-business purposes (leisure, personal projects, etc), independent tradesmen and small business, as well as larger institutional and independent fleet operators.
	Private	A vehicle operated by individuals.
Payload	cbm/kg	The load carrying capability (in cubic meters), and maximum cargo load (in kg).
	Pickup	This vehicle is a pickup truck.
Title	Last Mile	Vehicles used for the final step in the delivery process – delivery of packages/groceries/etc to their final

		destinations (individuals and businesses), from distribution depots.
	Service Van	Vehicles used for providing services to individuals, infrastructure, etc – across both public and private sector. The British Gas van in the below photo is a service van, for example.

Figure 11: Vauxhall Vivaro-e operated by British Gas charging at a 350kW (capable) DCFC at a Gridserve Forecourt. In the foreground is a VW ID Buzz charging at a 90kW (capable) DCFC.

Figure 12: A Vauxhall Vivaro-e operated by OVO Energy, and a private Porsche Taycan charging at 350kW (capable) DCFCs at a Gridserve Forecourt

Figure 13: Maxus eDeliver 9s, operated & fitted for refrigeration by Tesco, charge with EO Genius L2 EVSEs at a Tesco depot. Source: EO Charging

Figure 14: Ford e-Transits operated by Amazon at an Amazon depot. Source: EO Charging.

Figure 15: Mercedes eSprinter operated by Amazon. Source: Mercedes Benz

- Many LDVs within the above table share identical specifications (denoted by “ ”), and even identical appearances. This strategy is common within the automotive industry in general, especially as more vehicle manufacturers become aggregated through acquisitions by large conglomerates. Given the complexity of developing an optimal BEV drivetrain and vehicle system, referred to commonly within the industry as a "skateboard", it makes sense economically and logistically for a conglomerate to use that same skateboard design in offerings across multiple owned brands and/or manufacturers. In the case of LDVs available in the UK and EU, the automotive conglomerate Stellantis utilizes common BEV systems across its' brands Peugeot, Vauxhall and Citroen, and licenses that BEV platform to Toyota for their Proace LDV.

- LDVs such as parcel and delivery vans, primarily used within trade industries and corporate fleets, tend to be operated in distinct ways which reflect directly in technical specs:
    1. Predictable routes: Locations and routes covered in a given session (a day or a night), as well as specific distances and driving times, are predictable and oftentimes pre-determined for these vehicles. This is reflected in the lesser range and battery capacities, relative to new passenger EVs and trucks – e.g. for a van following a 150 mile route in a given day, a battery with only about 10% excess marginal cacpacity is necessary (such as the Stellantis offerings above).
    2. Long dwell time: These vehicle types generally run predictable distances over predictable time durations (referred to as shifts – working shifts, driving shifts, etc), and return to predictable locations when off-shift. Those off-shift locations may be depots for fleet vehicles, such as the Amazon vehicles shown above dwelling in Amazon distribution depots when not deployed, or individual homes and/or businesses such as a service station for a city maintenance vehicle or a house for a private handyman. Long dwell times between deployed shifts make the most economically efficient method of charging low power (UK definition "slow" or "fast") during the time the vehicle is parked, reflecting in technical specifications of AC charging capabilities being preferred over DC charging capabilities. For example, the Maxus eDeliver 9 vehicles, operated by delivery fleets such as Tesco, have 22kW AC charging but only 100kW DC charging. This is because the eDeliver 9 is typically charged via lower power AC charging when in the depot (such as the vehicles charging with EO Level 2 AC EVSEs in the Tesco hub pictured above), and only seldom (if ever) charges via DC in public during their routes.
    - *Range Extension via Forecourts*: Some fleet operators and individual commercial operators currently user EV charging forecourts and public charging infrastructure to effectively extend the range of their fleet

vehicles to cover certain routes or deployments. As can be seen in the above photos, operators of maintenance/delivery fleets such as British Gas, OVO Energy, and Royal Mail have corporate charging membership with Gridserve. This means, for example, that a British Gas technician driving a Vivaro-e with 205 miles of range can service multiple locations more than 50 miles apart in one day by stopping for a brief break at a charging forecourt to replenish their battery in about half an hour (assuming SOC from 0-80% of 35 minutes at a 100kW DCFC).

Review of Charging Mechanisms: Plugs & Cables

DCFCs

DCFCs are primarily used for en-route charging, within public charging networks and specifically within EV charging forecourts.

Figure 16: A 350kW capable DCFC made by ABB at a Gridserve forecourt. Plug type is CCS2, payment can be either contactless bank/credit card or a membership app/card.

Associated Standards:

CCS: Combined Charging Standard. A standard charging connector providing both AC and DC connections. Within markets such as North America, CCS1 connectors are used – these connectors combine the standard SAE J1772 (or IEC 62196 Type 1) AC charging connector with DC contacts. Within European and UK markets, CCS2 connectors are used – these combine the standard IEC 62196 Type 2 AC charging connector with DC contacts. CCS, either CCS1 or CCS2, is the dominant DC charging connector in NA, EU, and UK markets. Limited to 350kW power provision.

CHAdeMO: A DC fast-charging standard developed in 2010 by the Japanese CHAdeMO association. Currently dominant in the Japanese EV market, but very limited in NA, EU, and UK (In the UK, presently only the Nissan Leaf and the LEVX TX Taxi use CHAdeMO). Limited currently to 400kW power provision.

GB/T: A set of standards for AC and DC fast charging used in China. Not used outside of China.

DIN SPEC 70121: A German technical specification defining digital communication between an EV and a DC charging station.

AC EVSEs

AC EVSEs are primarily used for at-home charging, charging of fleet cars and vans with long dwell times, and destination charging. Given the ease of provisioning AC charging stations, availability of appropriate AC power sources within the residential space, and low cost of AC charging, these EVSEs can be found throughout many different EV charging applications including charging forecourts. These same benefits making AC EVSEs appealing also assure the presence of AC EVSEs going into the more and more electrified future.

Figure 17: 22kW EO Genius 2 AC EVSEs at an Amazon charging depot. Source: EO Charging

Associated Standards:

IEC 61851: International standards for AC conductive charging systems. Europe has a modification of these standards published as European standards (EN 62196). The UK also has a modification of these standards published as British standards (BS EN 62196). Limited to 7.2kW for single phase AC (32A @ 230V), 22kW for three phase AC (32A @ 400V), or up to 43kW (63A @ 400V) (only actively in the case of the Renault Zoe with options).

SAE J1772: North American standard for EV AC conductive charging systems. Derivation of IEC 62196 (international standard for EV conductive charging plugs – in which J1772 is titled Type 1). Limited to 19.2kW (80A @ 240V) power provision.

SAE J3068: North American standard for three phase EV AC conductive charging systems. Limited to 63A @ 600V (for example, can provide 133kW at 160A @ 480VAC on a three phase connection).

OCPP: Open Charge Point Protocol. An application protocol for communication between EVSEs and a central management system (CMS). It is an open protocol allowing EVSEs and CMS from different vendors to communicate with each other.

Pantograph

Pantograph charging is used specifically for HGVs, most typically for electric buses. Pantographs are automated, not requiring manual intervention from the driver in order to initiate charge, but are very expensive and subject to faults such as expensive + specialized maintenance, freezing and weather interference, and mechanical damage.

Figure 18: An ABB Pantograph automatically charging a bus. Source: ABB.

Associated Standards:

SAE J3105: Standard for automated connection devices (ACDs) that mate chargers with battery electric buses and HGVs. Limited to 600A (350kW) or 1200A (1200kW)

Review of Forecourt Amenities: Retail, Facilities & Service

Existing charging forecourts offer all of the amenities one would expect from a highway rest-stop facility and more – demonstrably in a more premium package. What follows is a review of some of the amenities offered by Gridserve (specifically herein at the Braintree, UK forecourt) and Shell (specifically at the London, UK forecourt):

Gridserve:

Amenity Type	*Offering*
Food & Grocery	M&S Food, Costa Coffee
Shopping	WHSmith
Services	Post Office
	EV showroom + Leasing + Test drives
	Exercise Areas (Indoor + Outdoor)
Facilities	Co-working / office pods
	Fast WiFi
	Restrooms
	Child area
	Pet area

Shell:

Amenity Type	*Offering*
Food & Grocery	Waitrose & Partners, Costa Coffee
Services	Fast WiFi
	Restrooms

Figure 19: Barista-made coffees from the Costa within a Shell Forecourt.

Figure 20: A technician maintains DCFCs at a Shell Forecourt.

Figure 21: A screen displays charging status of EVs on DCFCs at a Shell Forecourt.

Review of Forecourt Business Models: Capital, Partners & Energy Supply

Some key business issues and opportunities for charging forecourt developers and operators are detailed in pointed sections below:

Capital Intensive: Development of charging forecourts such as the Gridserve and Shell facilities pictured in this report is an expensive endeavour. In the case of Gridserve, they have seen over £34 million in investment from Hitachi Capital UK for site developments since 2020, including the Braintree forecourt pictured below. Gridserve is currently running a £1 billion programme planning to open 100 similar sites over the next 5 years, in partnership with Hitachi Capital UK. This capital partnership enables the medium-size organization Gridserve to provide charging forecourts to meet the growing demand within the UK, but not without dilution of ownership – Hitachi Capital is currently a ~19.63% owner of Gridserve. In the case of Shell, they do not have the same capital constraints and can develop sites from internal funding, sometimes converting existing Shell petrol forecourts to fully EV charging forecourts (as in the case of the London, UK Shell charging forecourt). However, Shell operates forecourt sites (both EV charging forecourts and traditional forecourts) under a franchise model – working with partners for each developed site to participate in site operation and/or development.

Development Challenges: Charging forecourt development requires land acquisition – either in the form of a purchase, lease agreement, or recycling of a previously owned asset. Shell, as mentioned above, owns and operates a vast network of service stations already – thus, the option for site conversion exists. Otherwise, a decision in land acquisition is largely driven by;

- Site selection: An ideal charging forecourt site is located along transit arteries on which continually pass a large volume of vehicles, preferably adequately spaced from other charging forecourts or concentrated EV charging facilities such that passing drivers would have a need to utilize a forecourt situated here. Further, a site needs to consider accessibility from the motorway for drivers of all vehicle types. Essentially, picture a rest-stop forecourt – perhaps with a slipway conveniently directing traffic from the highway.
- Power availability: Charging forecourt sites must consider availability of high power grid connections (33kV connection, devoted substations, etc) from the regional grid operator – is it possible to have a grid connection of adequate power to service the charging capacity of the forecourt at any particular location? What are the costs and lead times associated with that grid connection, if it is possible?

- Capital availability: Is capital available from financial institutions for these particular site developments? Is their capital available from government in the form of direct grants, or perhaps in the form of significant subsidies? Does the developing organization itself, or a parent company of the organization have working capital adequate to fund the site?
- Planning and Permissions: Granting of permissions from the regional governing body of a potential forecourt site can be onerous – in the case of Shell developing its' London charging forecourt, it took more than three years of planning to acquire all the necessary permissions from the London authority. In addition to required permissions from local government authorities and councils, there are also required permissions and approvals from the relevant grid operator in order to even be eligible for a grid connection.

Retail Partners: Entities developing charging forecourts do not necessarily have a business interest in operating all elements of the forecourts – often the retail and servicing of consumers (cafés, amenities, etc) is most effectively managed independently from the operation of the chargepoints and overall charging forecourt. In the case of Gridserve, WHSmith Travel runs all the retail facilities within their forecourts – with businesses such as Costa Coffee operating under the management of WHSmith. WHSmith and it's managed retail partners lease the forecourt facility space from Gridserve, and furnish a portion of revenues to Gridserve.
In the case of Shell, who are a global retailer of fuel, energy, and convenience retail, they have many different operating models globally. One of these models involves Shell owning the land and infrastructure and an operating partner operating one or more sites. On some service stations, Shell has offers from other retail partners such as Waitrose and Costa Coffee, with sales proceeds split between Shell and the operating partner.

Maintenance / Service Partners: In addition to Operating partners and Retail partners, forecourt developers have an interest in employing partners for service and maintenance of facilities. Shell, for instance, contracts with Vinci Construction for facilities maintenance in their London forecourt – when an equipment fault occurs, or routine maintenance of machinery is required, a Vinci technician or team is deployed to the forecourt site to provide service. The day-to-day management and maintenance of the facility is the responsibility of a full-time employee contracted directly by the Operating Partner, on behalf of Shell – that employee contacts Vinci according to facility and machinery requirements.

Tangential Business: Forecourt operators can leverage their visibility and position as trusted providers of essential energy & services to EV drivers through provision of services such as EV leasing programmes and EV OEM promotional opportunities. Gridserve, in partnership with Hitachi Capital UK, offers an EV leasing programme including EVs from Audi, BMW, DS, Mercedes, MG, Mini, Nissan, Renault, and Volkswagen – these leases also include zero-cost charging subscriptions to Gridserve forecourts within the monthly leasing payments. This leasing programme includes available test drives of popular passenger EVs at select Gridserve charging forecourts – a highly relevant and well targeted business, given access to an inherently participant customer base. Gridserve also offers to OEMs of EVs the opportunity to hold promotional events hosted at charging forecourts, such as the Nisan event which can be seen in Figure 6. These promotional events leverage the same benefit as the leasing business – access to a perfectly relevant potential customer base.

Enterprise / Corporate Customers: As more enterprises adopt electrified fleets of delivery, transportation, and service vehicles, utilization by corporate customers becomes a larger proportion of total site usage as well as a larger business opportunity. The preferred business model of enterprise customers operating an electrified fleet is a subscription/membership model, by which that enterprise customer can enrol its' entire EV fleet into a program permitting access to forecourt charging at either a fixed monthly rate or a preferential rate per kWh. Gridserve, for example, provides corporate charging accounts to British Gas, Royal Mail, and OVO Energy, among others. Shell provides corporate charging accounts to London taxi operators, Royal Mail, etc.

Marketing Strategy: Sustainability is an important aspect of forecourt operation for developers and operators, as well as an important marketing quality – presenting as a sustainable provider of energy and transportation services is important to distinguish EV charging forecourts within a crowded transportation industry. Devoted forecourt operators such as Gridserve and Shell Recharge take the optics solution of not providing petrol at charging forecourts, thus maintaining the messaging that they are catering for a new and independent industry segment.

Grid Services: Forecourt developers with battery storage built onsite, such as the Gridserve infrastructure detailed in the below section, have the ability to utilize energy price arbitrage to offer flexibility and capacity services to the grid. This creates an additional revenue stream independent from the actual operation of the forecourt.

Rental of Capacity: Forecourt operators such as Gridserve lease spatial capacity as well as energy capacity to Tesla, thus allowing for Tesla-vehicle specific supercharging at Gridserve forecourts such as the 6 Tesla Superchargers seen in Figure 7.

Forecourt Developer	*Development Partner*	*Site Owner*	*Charging Operator*	*Charging Tenant*	*Retail Operator*	*Retail Tenant*	*Maintenance Partner*
Gridserve	Finance: Hitachi Capital	Private Landowner	Gridserve	Tesla	WHSmith	Costa, M&S, Post	Vinci
Shell	Private Partner	Shell	Shell/Private Partner	None	Shell	Waitrose, Costa	Vinci

Figure 22: Sign in a Shell Forecourt highlighting sustainable construction and operation.

Review of Onsite Energy Generation & Storage, Technology

What follows is a listing of specifications of onsite energy generation and storage technologies installed at the Gridserve Braintree, UK forecourt location

- Onsite PV Solar Generation (on roof canopy pictured below): 227kW Peak.
    - 227kW Peak of solar production may seem a lot, but in reality it provides only sufficient power for the building (large two-storey building housing cafés, lounges, retail) – provision of power for EV charging would require for more generation capacity.
- Onsite battery storage: 6mWh, with a 5mW 33kV grid connection capable of import and export.
    - This battery storage capacity is in front of the electrical meter for site consumption, meaning it is directly connected to the distribution network (the electrical grid). This allows any available power in the storage battery to be directly sold back to the grid/utility. The selling of this energy back to the grid at preferential times is known as an arbitrage mechanism – energy is purchased at relatively low prices (when supply is abundant

and/or demand is low) and stored as charge within the battery ("energy import"), and sold at relatively high prices (when supply is constrained and/or demand is high) by discharging the battery back into the grid ("energy export"). Conversely, the ability to temporarily store energy on behalf of the grid is also an available revenue stream – this is known as capacity. The capacity market ensures security of electricity supply by providing payment for reliable sources of capacity, so provision can be guaranteed in the event of demand for energy exceeding supply of energy.

Figure 23: A line of private EVs charge on 90kW (capable) DCFCs at a Gridserve Forecourt, under a Solar PV canopy. A maintenance worker empties trash.

Figure 24: Foreground: An exercise bike providing power to the Gridserve Forecourt building. Background: A screen showing total green energy generated by the exercise bike.

Figure 25: Gridserve Forecourt 6mWh battery in shipping containers, storing input from a 5mW 33kV grid connection.

Figure 26: Gridserve Forecourt inverters providing power to DCFCs from grid source and battery storage.

Future Outlook of EV Charging Forecourts

Future EVs & Charging: Utilization & Duty Cycles, Types & Manufacturers

The source of the below charging forecourt demand model is a study by the Department of Electronic & Electrical Engineering at the University of Strathclyde in Glasgow, UK titled "Characterization of Electric Vehicle Fast Charging Forecourt Demand". Link and PDF available in §References & Resources. The model charging forecourt being considered is of 800kW capacity – providing 8 100kW DCFCs for EV charging, located in the UK. Modelled data is as of 2018 averages. The below figure serves as a reference to the parameters considered in the graphs that follow:

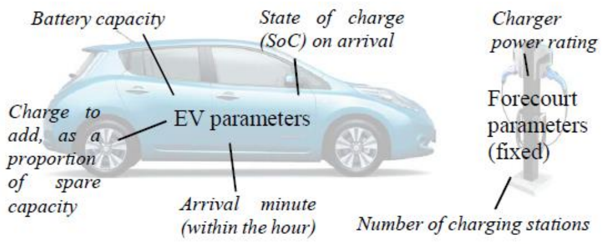


Figure 28: EV and Charging Forecourt Parameters influencing the demand profile and duty cycle of charging at a forecourt.

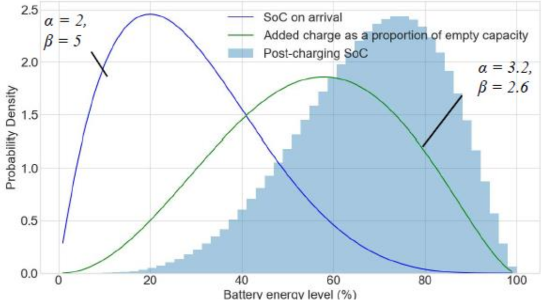


Figure 29: A graph compiled from averaged EV data in the UK, showing average SoC upon arrival to a charging forecourt is around 20%, and average SoC upon leaving is less than 80%, with an average amount of energy charged at about 60% of the total battery capacity. [We'll use these trends to analyse possible capacity requirements for future forecourts]

Considering the above model of EV SoCs using a charging forecourt, we can extrapolate a standard duty cycle of approximately 60% – meaning that an averaged charging session will replenish 60% of the vehicles' total battery capacity. Assuming this charging behaviour will not change considerably in the future (as it has not significantly since 2018, the date of this report), we can consider this a behavioural constant in predicting load growth with larger and more sophisticated EV models in the future.

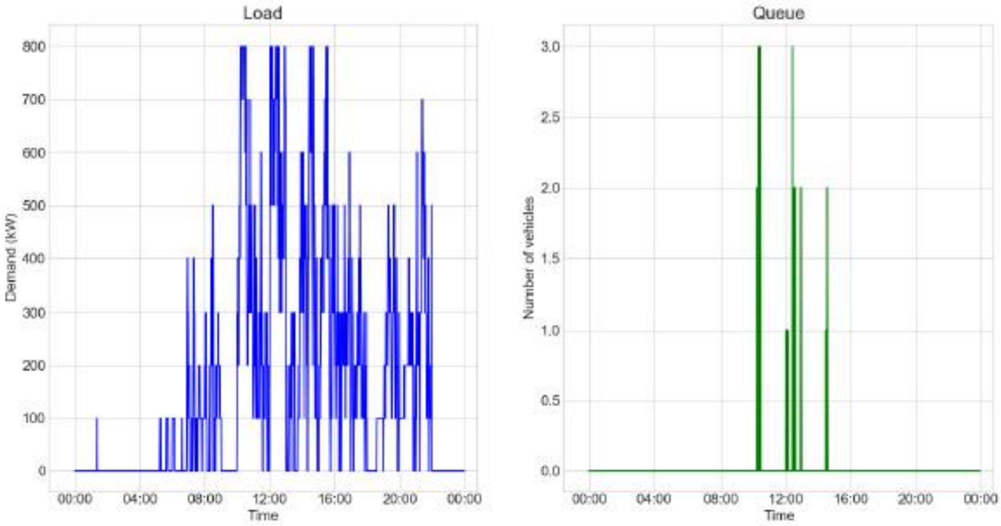


Figure 30: Total Site Load versus charging Queue length over an average Saturday, considering an 8 x 100kW forecourt.

The above model shows at left total site load being consumed only for brief spikes during the day, at times of peak usage – those peak load times correspond to peaks in vehicle queue lengths, at right. Given this data is modelled on an average Saturday's forecourt usage, it follows that peak usage will occur mid to late morning. Peak usage results in queues of vehicles waiting to charge and thus peaks in power consumption as all available chargepoints are utilized at full power, and then taper down as EVs reach higher SOCs.

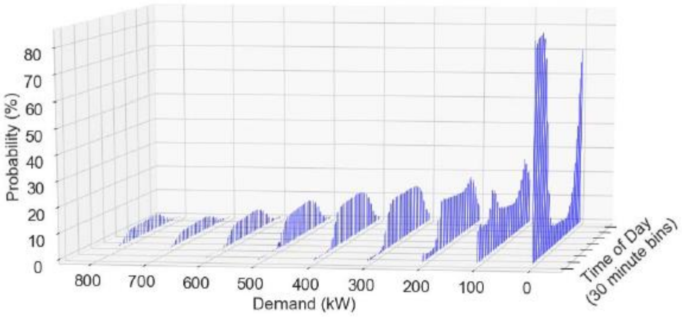


Figure 31: A 3D histogram showing probable total site load at different times throughout the day for an 8 x 100kW forecourt on an average Friday.

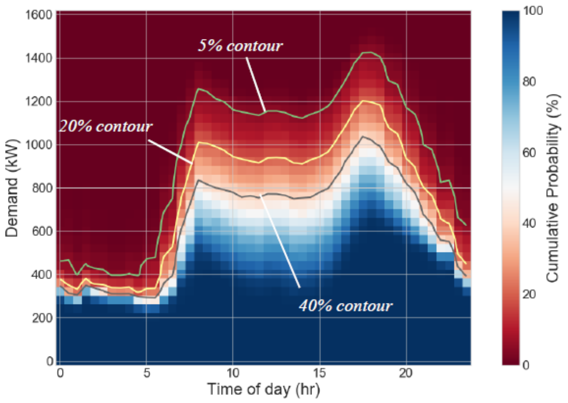


Figure 32: Assessment of impact of a charging forecourt on an existing electricity grid: Probability distribution of combined load profile for a 8 x 100kW forecourt supplied from an 11kV distribution feeder on an average weekday.

This model (Figure 31) shows a slightly different distribution in peak load timing than the model in Figure 30, due to the data projection being on a weekday as opposed to a weekend – peak load times correspond to commuting and working hours, with the majority of peak load occurring during the work day. However, the overall trend of peak load only being consumed during select time ranges is constant.

The above model (Figure 32) applies these average distributions of peak load on a charging forecourt to a real-life example of a forecourt being serviced from a local primary distribution feeder of the electrical grid. This connection of a charging forecourt to a non-devoted distribution feeder (a grid power source used by other consumers and facilities) is a common case, and one which will need to be dealt with increasingly as charging demand grows. It can be seen that, on any given day, there's a 5% chance that the peak will exceed 175% of the original peak (pre-forecourt) at the height of rush hour (17:30, here). A similar peak, perhaps in excess of feeder capacity, can be seen during the morning rush hour around 08:00. Even in this historical data model, it is clear that the massive and inconsistent demand of charging forecourts can be unsustainable for electrical grids. Smart grid technologies limiting electrical supply based upon real-time demand, and responding to grid overloading or signalling for capacity by curtailing available power, must be employed in order to smooth these excessive demand curves to enable further grid connections for charging infrastructure. Beyond technologies enabling grid flexibility, it will become increasingly necessary to have on-site battery storage to store energy from the grid during times of high supply and lower demand, and utilize that stored energy to supply EVs during times of peak charging demand instead of rely upon an already over-constrained electrical grid.

Referring to the below listing of some passenger EVs of interest being introduced in the coming years, and picking up the thread of the demand analysis based on charging behaviour (60% SoC duty cycle), it's clear by newly standard battery and charging specifications that forecourt power demand will only continue to grow:

- Charging Speeds: Given the average battery capacities shown below being far in excess of those considered in the study (average increase nearly 200%), and charging capabilities trending towards an average 150/200kW to meet this larger capacity, it's clear that DCFCs of 100kW no longer suffice. Gridserve and Shell already offer DCFCs in excess of 300kW, which we can take as a new standard. This means our model forecourt peak power capacity will triple – from 8 x 100kW DCFCs (800kW), to 8 x 300kW DCFCs (**2400kW**).
- Power Demand (Battery Sizes): If an average 60% SoC replenishment in 2018 was 22.2kWh (see IEA Global EV Outlook) and taking an average of the below near-future BEV models of 48kWh (60% of 80kWh, the average of standard BEV capacities below), it's apparent that charging forecourt

energy demand will be increasing to at least **200%**. This is, of course, not considering the ballooning volume of EVs on the road!

- Not accounting for EV uptake, required peak power rating of an equivalent charging forecourt of 8 DCFCs will increase **3X** in the next few years, while total power consumption will increase **2X**.

Future EV Makes: Passenger Cars

Manufacturer	*Model*	*Type*	*Price ($-$$$)*	*Passenger Capacity*	*Battery Capacity*	*Range (miles)*	*Charging Capability*
*LEVC**	*New TX*	*Hire BEV*	*$$*	*5*	*107*	*305*	*AC 22kW* *DC 250kW*
Fisker	Ocean	BEV	$	5	75	235	AC 11kW DC 200kW
Smart	#1	BEV	$	5	64	215	AC 7.4kW DC 150kW
Jeep	Avenger	BEV	$	5	50.8	180	AC 11kW DC 100kW
Subaru	Solterra	BEV	$$	5	64	195	AC 6.6kW DC 147kW
Lexus	RZ 450e	BEV	$$	5	64	195	AC 11kW DC 147kW
Polestar	3	BEV	$$$	5	107	305	AC 11kW DC 250kW
Lotus	Eletre	BEV	$$$	5	107	320	AC 22kW DC 350kW
Tesla	Model S Dual	BEV	$$$	5	95	355	AC 11kW DC 250kW
Rolls-Royce	Spectre	BEV	$$$	4	100	285	AC 11kW DC 200kW
Triumph	TE-1	BEV Motor	$	1	15	100	AC 6.6kW DC 50kW
Damon	Hypersport	BEV Moto	$$	1	20	200	AC 6.6kW DC 30kW

*LEVC TX next generation specifications are estimated, based on 2023/2024 Polestar 3 specifications. Logic behind this estimation is possible shared BEV platform between manufacturers owned by the same entity, Geely (Polestar is a brand of Volvo, who is owned by Geely, since 2010. LEVC is owned by Geely, since 2013. This strategy of sharing BEV platforms across multiple brands/manufacturers owned by a common conglomerate is common – more on that strategy in the points of analysis under "Current EV Makes: LDVs").

Future EV Makes: LDVs (Parcel Vans, Last Mile, Service Vans)

Manufacturer	***Model***	***Customer Types***	***Payload***	***Battery Capacity***	***Range (miles)***	***Charging Capability***
Stellantis	Ram ProMaster		17cbm/4.2t	79kWh	200	22kW AC, 50kW DC
Mercedes	eSprinter	Amazon	13.8cbm/4.25t	113kWh	300	9.6kW, 115kW DC
Ford	E-Transit	Amazon	15.1cbm/1.1t	74kWh	236	11kW AC, 125kW DC
GM BrightDrop	Zevo 600	Walmart FedEx	17cbm/2.2t	165kWh	250	10kW AC, 120kW DC
	Zevo 400	Verizon	11.33cbm/2.2t	" "	300	" "
Rivian	EDV 700	Amazon	19.82cbm	135kWh	201	11.5kW AC, 220kW DC
	EDV 900	Amazon	25.49cbm	" "	150	" "
Arrival	L		19.82cbm/2t	133kWh	211	11kW AC, 120kW DC
Canoo	MPDV1	Walmart	5.66cbm	80kWh	230	100kW DC
	MPDV2	Walmart	12.75cbm	80kWh	190	100kW DC
	LDV	Walmart	3.40cbm/1.5t	80kWh	250	100kW DC
Udelv	Autonomous	Delivery Companies	7.65cbm/2t	160kWh	300	9.6kW AC, 200kW DC
Chevrolet	Silverado EV	Private/Trade	Pickup	200kWh	400	9.6kW AC, 350kW DC
Ram	1500EV	Private/Trade	Pickup	200kWh	400+	350kW DC
Tesla	Cyber Truck	Private/Trade	Pickup	200kWh	500	19.2kW AC, 1mW DC!
Lordstown	Endurance	Fleet	Pickup	109kWh	250+	11kW AC 110kW DC

Legend:

Parameter	***Data***	***Definition***
Customer Types	Trade/Fleet	A vehicle commonly operated by independent tradesmen (e.g. plumbers, electricians, handymen, etc small businesses), or by larger fleet operators such as delivery companies, utilities, service companies, etc.
	Private/Trade/Fleet	A vehicle operated by individuals for primarily non-business purposes (leisure, personal projects, etc), independent tradesmen and small business, as well as larger institutional and independent fleet operators.
	Private	A vehicle operated by individuals.

Payload	cbm/kg	The load carrying capability (in cubic meters), and maximum cargo load (in kg).
	Pickup	This vehicle is a pickup truck.

Future EV Makes: HGVs (Trucks)

Manufacturer	*Model*	*Type*	*Payload*	*Battery Capacity*	*Range (miles)*	*Charging Capability*
Tesla	Semi	Tractor	36t	~900kWh	500	1MW DCFC
Nikola	Tre	Tractor	19t	733kWh	350	240kW DCFC
	Tre Hydrogen	Tractor	19t	120kW H 140kWh	500	
Tevva	TEV75B	MDV	3t	105kWh	141	22kW AC
	TEV75BH2 (Hydrogen)	MDV	2.7t	9kg Fuel Cell, 112kWh Battery	354	22kW AC

Future EV Makes: Buses

Manufacturer	*Model*	*Type*	*Passenger Capacity*	*Battery Capacity*	*Range (miles)*	*Charging Capability*
Mercedes	eCitaro G	Transit	145 people	441kWh	105	300kW Pantograph
Ebusco	2.2	Transit	150 people	500kWh	280	150kW DCFC, 350kW Pantograph
Yutong	U12	Touring	70 people	422kWh	250	120kW DCFC, 300kW Pantograph

We can now run the same demand analysis calculation for future forecourts with future passenger vehicles as we did above, yielding an expected forecourt power rating increase of **300%** with forecourt power consumption increase of **200%** on an equivalent 8 x DCFC site, but now considering also future LDVs, HGVs and buses:

- Charging Speeds: Next generation LDV average charging speeds are not in excess of next generation passenger EVs, but next generation HGVs and buses commonly trend over 350kW. We can thus calculate our forecourt peak power capacity as (8 x 350kW DCFCs) **2800kW**.

- Power Demand (Battery Sizes): Taking the average battery size of next-generation LDVs as 145kWh (based on above future LDV table), the average battery size of next-gen HGVs as 399kWh (based on both above HGV tables), and the average battery size of next-gen buses as 454kWh (based on above buses table), we can combine all of these with the near-future passenger BEV models to arrive at a new per-vehicle average battery capacity of 261.5kWh. Using the average 60% SoC consumption rule, we arrive at an average energy demand of **157kWh** per vehicle. This figure puts possible future energy demand at **700%** that of 2018 demand. This estimate is of course flawed, but provides an estimate of the massive energy demands we may see at future charging forecourts.
- Not accounting for EV uptake, but accounting for forecourt usage by buses & trucks, required peak power rating of an equivalent forecourt of 8 DCFCs will increase **3.5X** in the next few years, while total power consumption will increase **7X**.

Autonomous Vehicles: Autonomous technology is advancing at a rate by which adoption of computer system driven vehicles throughout many different sectors can be seen as an inevitability in the relatively near future. Especially in vehicle transportation sectors involving long distances and predictable routing, such as freight haulage and parcel delivery, we will soon see operation of driverless electric vehicles on the same transportation infrastructure as that which exists for vehicles today. This means an expectation and market opportunity for charging forecourts to service these autonomous vehicles, for which infrastructure offerings will need to be made available to cater to particular requirements of driverless electric vehicles:

- Fully automated charging mechanisms requiring no manual intervention, such as static wireless charging and dynamic wireless charging.
- Devoted or guidance assisted parking areas.

Future Charging Mechanisms: Wireless, High Power, Battery Swap

Static Wireless Charging

Wireless charging, also known as inductive charging or wireless power transfer, is a technology enabling electric vehicles to receive (and transmit) charge with no physical contact (no cables) nor manual interaction. Benefits include increased convenience, durability, and reliability, as well as enabling technologies such as autonomous vehicles and improving the accessibility of V2G. See Appendix A for more information.

Associated Standards:

SAE J2954: Primarily North American standard for Magnetic Frequency Wireless Power Transfer ("MF WPT") for EVs, power classes 3.7kW, 7.7kW, 11kW.

ISO 19363: International standard for MF WPT for EVs, power classes <11.1kW, frequency 79 – 90kHz.

IEC 61980: International standard for MF WPT for EVs, specifically Safety, EMC & EMF (61980-1), Communication (61980-2), and GA requirements (61980-3)

ISO 15118: International vehicle to grid communication interface, for bi-directional EV charge/discharge.

Dynamic Wireless Charging

Dynamic wireless power transfer uses inductive power transfer coils embedded in roads or highways to charge vehicles while they are actively moving over those roads, the chief benefit of which is effectively enabling range extension of EVs without increase in battery by continually charging without a need for stopping. See link to electreon in §References/Resources for more.

Associated Standards:

SAE J2954: Primarily North American standard for Magnetic Frequency Wireless Power Transfer ("MF WPT") for EVs, power classes 3.7kW, 7.7kW, 11kW.

High Power Charging

As electric HGVs such as semi-trucks and buses develop to meet utilization patterns, with larger batteries and extended duty cycles, charging mechanisms supporting in excess of 1MW are becoming more necessary. CCS, being limited to 350kW, is not appropriate for this application. And pantograph charging systems are proving not to be a universally applicable solution, so a new solution for charging at these power levels must be developed. Presently, no single standard has yet been adopted in the industry – the most likely next standard is MCS, below.

Associated Standards:

MCS: Megawatt Charging System: A charging connector under development for HGVs (vehicles with large batteries). Rated for up to 3.75MW (3000A at 1250V DC). Being developed by the CharIN organization, with ongoing adoption by SAE as the J3271 standard and IEC as the 63379 standard.

Battery Swapping

A technology allowing EVs to swap low SoC or dead batteries for fully charged batteries in a matter of minutes. This method requires the OEM of a vehicle to design in a swappable vehicle battery, as well as introduce infrastructure and battery modules to cover customer range expectations. There are not currently any standards for battery swapping, and it is thus very OEM specific and still in the R&D phase. For more information, see link to NIO Power Swap in §References/Resources.

Future Amenities: Retail, Facilities & Service

Amenities in future charging forecourts will need to evolve with consumer trends towards digitalization and mobilization, sophistication of retail offerings, and convenience of aggregated retail offerings. Services such as Amazon Fresh where shoppers can interact with retail / grocery / café outlet through a mobile application, and use said application to handle all aspects of the shopping process from item selection to checkout, will be expected to be incorporated seamlessly into the forecourt retail experience. In the larger view of a forecourt, essentially resembling a shopping mall with an array of different retail offerings, users will view the forecourt as a single entity and will want to be able to interact with it as such in a convenient fashion in line with their experience charging. This ideally will take the form of a forecourt application through which users can search across all available retail offerings, purchase from any vendor onsite directly through the application either via a forecourt account or a linked payment account, and even order shopping or food for direct delivery to their charging vehicle.

Furthermore, charging forecourts of the future will need to support amenities associated with longer dwell times – meaning users spending more time in the forecourt facilities, including using the forecourt as an overnight location. This could include hotel offerings, formal restaurants, and built out gymnasium and co-working facilities. With longer distances being covered, and multiple different vehicle/driver industries combining, the driver expectation for facilities available at a forecourt will be more thorough.

As mentioned, consumer trends are shifting away from traditional offerings as one might expect at a forecourt of old (gas station) towards digitalization and efficient hybrid ecosystems. This table gives an overview of some of these consumer trends as they apply to customer expectations from a forecourt:

Attending to multiple customer needs

	What are their needs?	What to offer?
Flex-working	Wants a comfortable place to work outside home Values ambience and experience	Sophistication in food & beverages, coffee and bakery Digital and value-added services Exclusive/VIP area Frequent-visitor deals
Agile driver	Wants to streamline the fueling process If possible, avoid getting out of the vehicle	Access to priority/fast-lane Package collection from e-commerce All-in-one e-payment and transactions
Digital native	Wants to interact through their smartphone	Mobile app platform Digital services Targeted marketing Package collection from e-commerce
Socializing	The station is a meeting point	Will probably spend in convenience store and/or coffee and bakery Entertainment services Parking
One-stop ecosystem	Wants efficient use of time One stop for multiple purposes	Convergence of retail stores Banking, pharmacy, grocery, laundry Package collection from e-commerce Cross-selling bundles Parking

Figure 33: Future Forecourt Customer Retail Needs, Source: Arthur D. Little analysis.

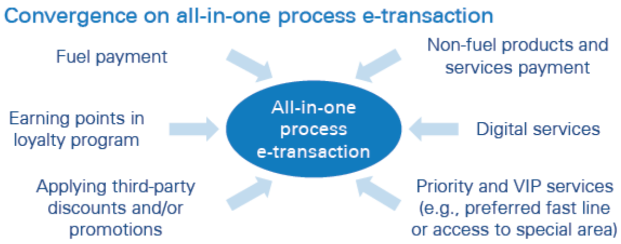


Figure 34: Aggregating all available services into mobile application based transactions. Source: Arthur D. Little analysis.

Future of Business Models: Capital, Partners & Energy Supply

Capital Intensive – Offgrid Development: As the necessity for local generational sources such as PV solar and wind turbines grows, as well as the now apparent necessity for charging forecourts to have a large installed base of battery storage, requirements for capital expenditure are increasing drastically. Although continual improvements in microgrid and renewables technology drive the cost per kWh of local generation and energy storage (battery storage) down over time, the demand for consumption of that energy is increasing ever faster. Furthermore, necessity for microgrid energy capacity increases along with EV charging demand given 1. Lack of capacity from electrical grids for provision of sufficient energy with required supply reliability, and 2. EV charging requirements in further isolated locations along long-distance transit routes such as intercity and interstate highways. It is clear from the logistical and technological requirements of future forecourts that not only the most sustainable but also the most economically viable solution for energy supply will be microgrid and local generation – with already strained electrical grids and inordinately long grid runs to remote locations along transit arteries, finance models for forecourt development will need to evolve. We may expect devoted finance suppliers such as banks and investment groups with funds specifically designed for charging infrastructure and forecourts, and government subsidies + grant opportunities available for forecourt developments.

Battery Storage Economies: A separate note on the advancing economies of battery storage development to highlight the trend of utilizing recycled and EOL (end-of-life) batteries from the vehicle industry to store electricity. Within electric vehicles (BEVs of all types, as well as PHEVs and in the future FCEVs), batteries are subjected to strained life cycles – meaning frequent charging and discharging of the cells in the battery pack often involving deep cycles (discharged to a very low state). This results in batteries only lasting a limited amount of time/miles driven in EV applications, before needing to be replaced in order to maintain EV range. An average percentage of battery range degradation at which an EV may be expected to have a battery replacement is 70-80% of initial capacity. These extracted cells are still fully functional, with forward lifespan equivalent to if not exceeding their already expended lifetime, however at a lower power density (less energy per unit weight). For applications in which weight and volume are not of utmost importance, chiefly energy storage, these second-life recycled batteries represent an ideal economic proposition. For more information, see "Feasibility of utilising second life EV batteries: Applications, lifespan, economics, environmental impact, assessment, and challenges" in §References/Resources.

Pricing of Charge: Presently, pricing for charging has high elasticity due to relatively limited supply availability – the most important factors for consumers are accessibility and reliability. A per kWh energy price deviation of 33% (in the case of Gridserve ultra-rapid pricing [£0.64] versus Shell Recharge ultra-rapid pricing [£0.85]) does not significantly impact an EV drivers' decision to charge at one location versus another, given what is most important is the location of the forecourt along the travelled route of the EV driver as well as the reliability that charging will be available and sufficient in power to cover the drivers' journey. As demand for charging infrastructure grows, and charging forecourts become more dense, pricing for charging will become more inelastic – reliability and accessibility will of course continue to be important, but EV drivers will have more choice around which specific forecourt or charging infrastructure they may use to service a given journey. Thus, the cost of energy generation and distribution to the forecourt operator, as well as the operational costs of the forecourt and the capital costs in developing the forecourt, will become more important in order to provide sustainably competitive pricing to consumers.

OEM Specific Fuelling: BEVs, which are standardized on a set of charging standards for supply with AC EVSEs and DCFCs, are the dominant non-ICE vehicle technology and will likely continue to be for the foreseeable future. There are, however, other technologies which may have a presence in the future of road transportation including battery swapping and hydrogen fuel cell. For more information on battery swapping, see the above section on battery swapping or see the reference section for NIO. Hydrogen vehicle technologies (also called FCEVs – Fuel Cell Electric Vehicles) are powered by electric motors backed by batteries just as BEVs, but are able to produce electricity onboard through a chemical reaction between hydrogen stored in onboard fuel cells and oxygen in the environment. Emissions are only water vapor and warm air, and electric vehicle range can benefit greatly from onboard hydrogen power generation, but the hydrogen infrastructure required for refuelling can be complex and energy intensive – the process for producing hydrogen is known as electrolysis, and may be either localized at the site of fuelling (such as a forecourt) or located at an industrial facility and hauled in via truck or train. Demand for these non-standardized fuelling solutions may grow for some charging forecourts, so accommodation of this infrastructure on a case-by-case basis will be necessary.

Enterprise / Corporate Customers: As more fleets across all industry sectors electrify, the enterprise customer category may become the most important offering for many forecourt operators.

Airports: Building on Airport land, serving as a hub for EV travellers but also for transport servicing from the airport. Gatwick car rental site being moved next to forecourt – rapid charging availability makes sense to optimize fleet uptime for rental business.

Non-fuel Revenues: A major component of future forecourt revenue generation will come from sources outside of direct energy supply including retail, food, amenities, entertainment, and services. The below graphics, although specifically sampling traditional petrol forecourts, serve to show this trend at present and how it will evolve going forward:

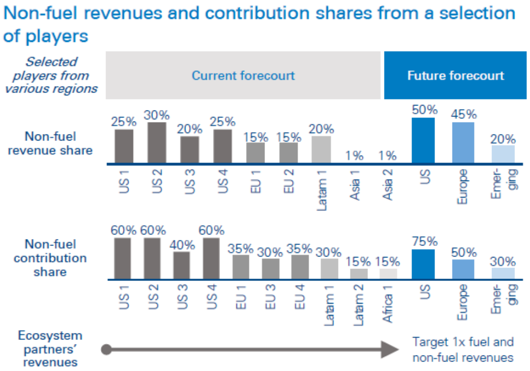


Figure 35: Forecourts are diversifying revenue streams, with direct fuelling/charging revenue decreasing in overall share. Source: Arthur D. Little analysis.

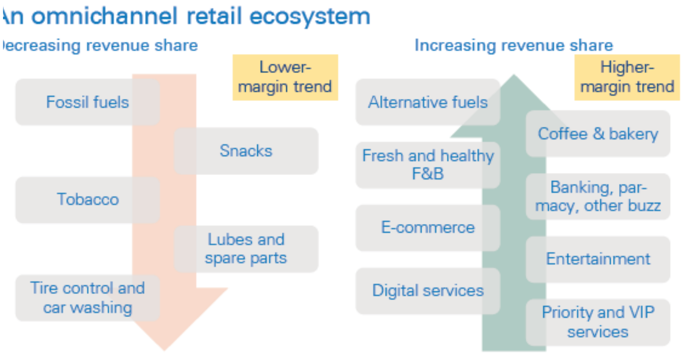


Figure 36: Revenue sources forming majority shares in future forecourts will not resemble those of traditional forecourts. Offerings such as food, services and entertainment can provide higher standard margins than energy supply. Source: Arthur D. Little analysis.

Marketing and Site Planning: Creating a pleasant atmosphere emanating sustainability and accessibility is key to the successful and widespread adoption of charging forecourts in the future. Charging forecourts should make an attempt at naturalism in their implementation with the surrounding landscape, and be positioned at points along key arterial transit routes at which 1. Ingress and egress of traffic between the forecourt and the motorway enables natural traffic flow with high visibility of services for passing traffic, 2. Power and services required can be provided in an unobtrusive fashion, 3. Construction and operation can successfully operate as sustainably and as environmentally as possible.

Figure 22: A verdant concept for an ultra-rapid charging forecourt along a major motorway. Source: Be.EV, Manchester, UK.

Figure 38: A sustainability and landscaping focussed concept by Arup architects for next generation Gridserve forecourts.

Required Skills & Training

Development, installation and operation of effective charging infrastructure requires a specific host of capabilities from involved engineers, technicians, and maintenance workers. A similar array of specific capabilities is required from those developing and operating fuelling forecourts and motorway services. And thirdly there is another distinct set of necessary capabilities from those developing and operating retail amenities, food establishments, and hospitality facilities. The charging forecourt of the future combines all of these capabilities into one massive set of requirements for staff involved in all aspects of making charging forecourts a universal reality:

Infrastructure Development & Installation:

- Civil Engineering: For site planning and integration with road infrastructure. Motorway and traditional "rest-stop" forecourt development experience.
- Electrical Power Engineering, Grid: For design of power distribution from the electrical grid to service necessary forecourt capacity. Grid connection and power distribution systems design experience.

- Electrical Power Engineering, Microgrid: For design of on-site generation from PV solar, wind turbines, and battery storage mechanisms serving both on-site generation and any grid tie power sourcing. Renewables generation / energy storage / LV distribution systems design experience.
- Electrical Installers, grid: For installation of grid connection and high voltage power supplies and routing. Registered electrician with grid works / substation / etc experience.
- Electrical Installers, microgrid: For installation of PV solar, wind turbines, and battery storage – as well as the feeder/distribution systems therein. Registered electrician with renewables generation / energy storage / LV distribution experience.
- Electrical Installers, EV Charging: For installation of charging infrastructure. Registered electrician with EVSE installation experience.
- Construction Contractors: For management of roads, parking and infrastructure construction site. Registered contractors with forecourt/road infrastructure experience.
- Construction Workers: For construction of roads, parking and infrastructure. Experience building forecourt/road infrastructure.
- Site Planning Lawyers: For dealing with permitting, permissions and ownership of site from planning through to construction. Experience in real estate and road infrastructure development projects.
- Site Development Finance, Accountants: For accounting finance of site development and construction. Real estate / infrastructure finance experience.

Facilities Development & Installation :

- Civil Engineering : For planning and design of forecourt facilities including retail, café, restrooms, lobbies, etc. Retail / shopping / public facilities design experience.
- Hospitality / Shopping Mall Planning : For planning of shopping and hospitality aspects of forecourt facilities such as retail stores, restaurants, hotels, gymnasiums, etc. Experience in planning of shopping malls, resorts, and convenience stores.
- Architects : For design of forecourt facilities and grounds. Experience in design of shopping malls and resorts, as well as road infrastructure and rest-stops.
- Landscape Architects : For design of forecourt grounds, focus on sustainability and continuity with landscape. Experience in usage of local flora and sustainable + verdant public infrastructure.
- Environmental Science : For ensuring development and operation of the charging forecourt is done in a sustainable way coexisting with the local environment.

- Electrical Installers, Facilities power : For installation of low voltage power supply networks. Registered electricians with large facilities installation experience.
- Construction Contractors : For management of facilities construction site.
- Construction Workers : For construction of facilities.
- Building Development Lawyers : For dealing with permitting, permissions and safety of facilities site from planning through to construction. Large retail site dev experience.

Forecourt Operation:

- Energy Management : Selection and operation of energy management software for Energy Services, Load Balancing, etc. Experience with energy services and grid interaction, and usage of relevant software suites.
- Logistics Managment : Management of vehicle traffic flow and infrastructure utilization. Experience in public vehicles logistics.
- Electrical & Infrastructure Maintenance Technicians : For continual servicing of charging infrastructure and service facilities. Experience in traditional forecourt service and/or public transport infrastructure maintenance.
- Infrastructure Maintenance On-call Service : High-availability electrical maintenance companies servicing given infrastructure locality.
- Finance & Accounting : Accounting of energy usage and revenues.
- Legal Counsel : On-retainer lawyer with experience in public transport infrastructure and EV charging specifically (if available).
- Vehicle-specific Engineers : Technicians with capabilities to service BEVs and possibly FCEVs.

Amenities Operation:

- Hospitality Management
- Facilities Management
- Hospitality Workers (Restaurants, Service, etc
- Custodian Staff
- Handymen

Appendix A: Wireless Charging with Electric Green

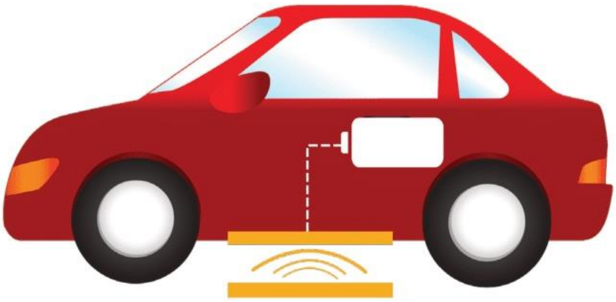
Wireless electric vehicle charging

Enabling cost-effective and effortless charging infrastructure

The rollout of EVs penetrates all areas of existing road vehicle use. While the majority of EVs will be driven by the public, organisations which operate fleets of vehicles will be significant. With an increasing total number of EVs, plug-in charging stations will become cumbersome features of carparks and depots, with charging cables presenting a multitude of hazards. Wireless EV charging technology is a simpler and more convenient way to charge an EV, without a cable in sight.

Wireless charging technology

Instead of transferring power to the vehicle battery via a cable, wireless systems achieve the same thing but with greater convenience for the EV user. Charging is enabled through a high frequency inductive coupling established between coils inside a groundpad and on-vehicle pads, then connected to the EV battery.



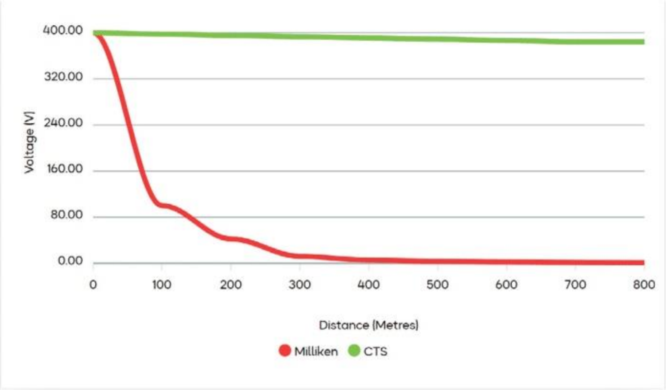
The situation

Wireless charging takes place at a frequency of 85kHz, 1700 times higher than the grid. It's very difficult to send this high frequency electricity over long distances without significant voltage drop.

As a result, with conventional cable, the converters required to produce the 85kHz signal are restricted to only serving one or two parking spaces at a time, resulting in a high capital and operational expenditure when dealing with multi-chargepoint requirements (e.g. fleet charging). For this reason, many companies struggle to deliver a scalable, cost-effective version of wireless charging infrastructure.

The solution

The Electric Green solution utilises benefits of CTS technology to make installation far more efficient. When comparing a 100 metre sample of CTS and conventional cable using a stable 50A current and 400V, the conventional cable causes the voltage to drop by 65% at 85kHz whereas CTS only has a 5% voltage drop. Therefore the converter doesn't need to be located near to every groundpad, so no street furniture is required near the parking lot.



Output voltage of CTS in comparison with Milliken cables

The Electric Green solution delivers many benefits including:

- ✓ Significant economies of scale ideal for fleets, depots, taxi ranks etc
- ✓ No street furniture at point of charge
- ✓ Increased system availability through multiple redundant power supplies
- ✓ Heat recovery from a centralised converter
- ✓ Modular growth – easy to expand

The solution

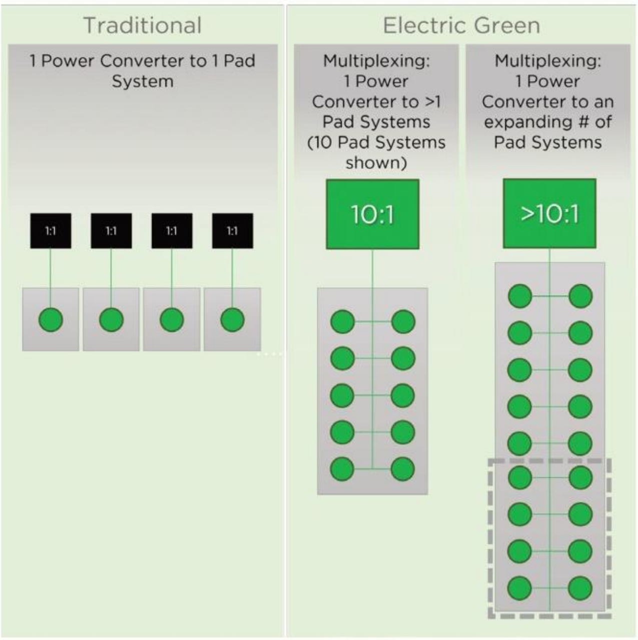
While private vehicle owners find the wireless charging process more convenient and easier than plug-in. For instance, taxi drivers and ambulances do not want the charging process to impact their service availability and revenues. Wireless charging 'opportunistically' enables them to top up their batteries while they go about their everyday jobs. Fleet operators also want the reliability and reduced running costs offered by wireless infrastructure.

All charging pads across the parking area can be supplied from a central power supply point. This reduces the number of expensive power electronics components and makes maintenance and heat recycling much easier. Parking areas can be described by their groundpad to converter ratio, which is where Electric Green has its impact.

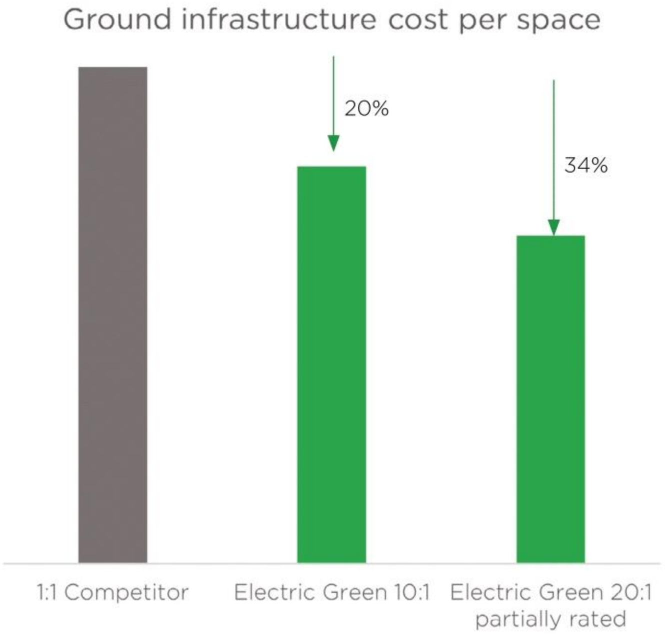
The Electric Green solution enables economies of scale, yielding a 20% reduction in the end-to-end cost of purchasing and installing the technology for a wireless charging parking space in a centralised system. A 34% reduction can be made for a space in a car park where 50% of the spaces are charging vehicles at one time, reflecting that the car park may not be at capacity, or vehicles parked there do not require instantaneous charging. In addition, the grid connection requirement is reduced. We refer to this as power multiplexing with prioritisation and load assessment.

This evaluation does not consider operational costs, expected to be significantly lower for Electric Green due to the ease of maintenance and physical separation of the centralised power supply.

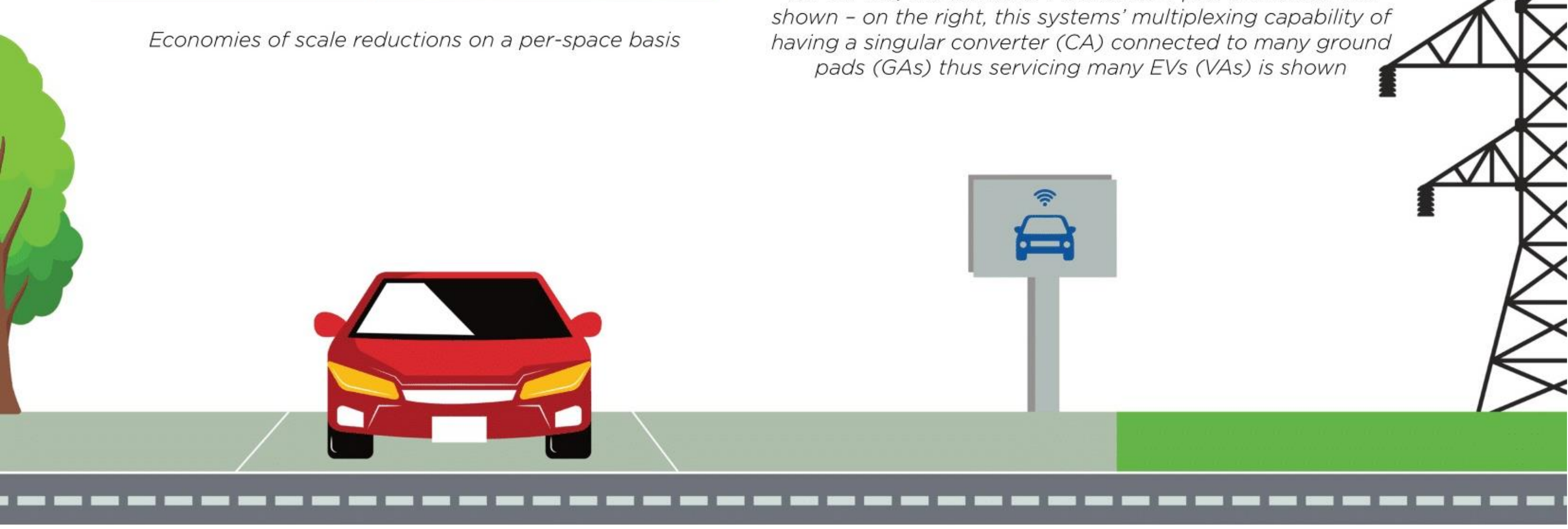
ELECTRIC GREEN POWER DISTRIBUTION ROADMAP



Economies of scale reductions on a per-space basis

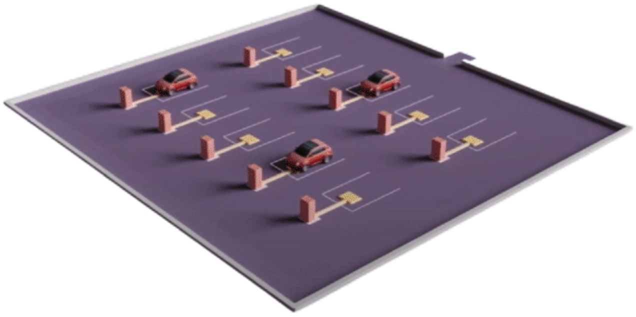


On the left, the standard 1 converter: 1 pad architecture is shown – on the right, this systems' multiplexing capability of having a singular converter (CA) connected to many ground pads (GAs) thus servicing many EVs (VAs) is shown

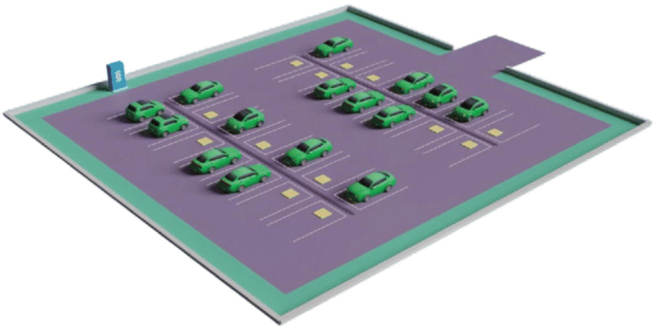


Wireless electric vehicle charging

Technical system overview - an overview of the Electric Green system



Traditional wireless



Electric Green

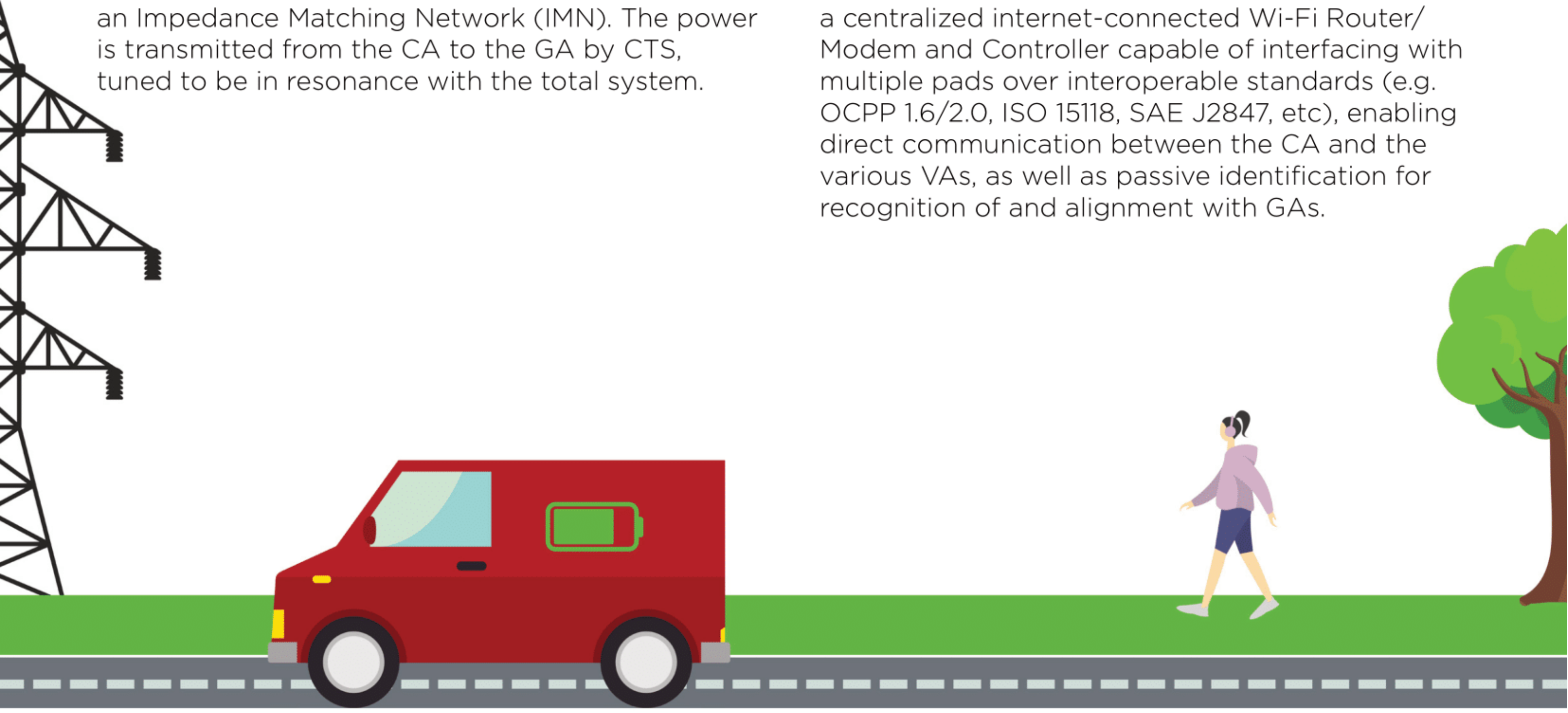
The Electric Green solution is a Magnetic Frequency Wireless Power Transfer (MF-WPT) system as classified by the key standards for wireless EV charging (SAE J2954 and IEC 61980-1). This MF-WPT system consists of two ground mounted components: the central assembly (CA) and the ground assembly (GA), and one on-board vehicle assembly (VA). Unlike a standard WPT charging system, which is constrained to a 1 power converter to 1 pad system relationship, the Electric Green system uses a common backbone enabled by CTS cable to service multiple pad systems from one central power converter allowing the so called "multiplexing" schema.

The CA has a bidirectional power flow capability connected to the local power grid. It consists of a power frequency converter, a Power Factor Correction scheme, a DC-AC inverter, a filter, and an Impedance Matching Network (IMN). The power is transmitted from the CA to the GA by CTS, tuned to be in resonance with the total system.

The GA consists of a coil generating an electromagnetic field at 85kHz, creating an inductive coupling to the VA coil to transfer magnetic energy over the air gap between these two coils. The power flow can go in both directions allowing charging of the vehicle battery or discharging to provide local power supply, a concept termed vehicle to grid (V2G).

The VA consists of a coil inductively coupled with the GA for power transfer, an IMN, a filter, and a power converter interface with the EV battery. The controller is capable of communicating with the CA as well as with the EV's on-board charger for power flow control. The controller then interfaces with any existing User Interfaces (Safety Systems & Alignment) for charge initiation.

The communications medium of the system is a centralized internet-connected Wi-Fi Router/Modem and Controller capable of interfacing with multiple pads over interoperable standards (e.g. OCPP 1.6/2.0, ISO 15118, SAE J2847, etc), enabling direct communication between the CA and the various VAs, as well as passive identification for recognition of and alignment with GAs.



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Shell Recharge: Shell Recharge Fulham Road

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General Forecourt Business Insights: The Forecourt of the Future, Arthur D. Little

Dynamic Wireless Charging: electreon

Battery Swapping: NIO Power Swap

Second Life Batteries: Feasibility of utilising second life EV batteries Applications, lifespan, economics, environmental impact, assessment, and challenges from CEEA, Light and Energy Solution Sdn Bhd. (PDF also available)

In researching for this report, we have conducted interviews with Gridserve and Shell employees, and have had facility tours of the Gridserve Braintree forecourt as well as the Shell Recharge Fulham Road forecourt (both in the UK).