Guidehouse INSIGHTS

White Paper

UK Roadmap for Residential Vehicle-to-Grid (V2G)

Leveraging learnings from the Powerloop V2G Trial

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Executive Summary

The increasing share of wind and solar energy to meet net zero commitments poses challenges to the grid due to the variable nature of its generation. Renewable generation is in general dependent on external factors such as the weather and so cannot be increased or decreased at will to meet demand for electricity. As the number of electric vehicles is predicted to continue to rise, driven by the UK's ban on new fossil fuel-powered vehicles in 2030, vehicle-to-grid (V2G) can play an important role in providing grid flexibility services and increasing resilience at a local level. In the current economic and political climate, rising energy prices and the need for resilience have become increasingly important national issues that can be addressed to a degree with the mainstream adoption of V2G.

In the current economic and political climate, rising energy prices and the need for resilience have become increasingly important national issues that could be addressed to a degree with the mainstream adoption of V2G.

In 2018, the Office for Zero Emission Vehicles (OZEV), the Department for Business, Energy and Industrial Strategy (BEIS), and Innovate UK provided funding of £20 million for innovative trials that develop future V2G products, services and knowledge. Powerloop was one of the trials awarded funding as part of this competition. Powerloop is a revolutionary trial assessing the feasibility of residential V2G. The trial offered a bundled proposition, including an EV car lease, bi-directional V2G charger, a smart tariff and an app, to 135 customers in the UK aiming to:

1. Gain insights into **customer needs, driving behaviours**, and what **propositions** they are attracted to.
2. Collect data and **collaborate with the local Distribution Network Operator (DNO)** to understand and improve the process of connecting V2G to the grid and inform on the **opportunities to provide flexibility services** at a local and national scale.
3. Build an **optimisation and dispatch platform** allowing the charge and discharge to be scheduled, controlled remotely, and aggregated across multiple devices.
4. Develop a **business model that delivers value** to all parties in the value-chain.

This paper primarily focuses on the second objective and through the analysis of trial findings and interviews with all main DNOs in the UK **presents a roadmap for how V2G can become a wide-scale future offering in the UK**, taking particular note of the challenges and opportunities perceived by DNO.

Powerloop has examined in depth the connection process for exporting distributed energy devices working closely with network designers from UK Power Networks (UKPN), the DNO partner on the trial and gathering feedback from customers. Areas of improvement were identified and incorporated into UKPN's Smart Connect Portal launched in 2021, designed to improve the ease, speed and efficiency of assessing connections and provide a higher level of transparency of the connection process stages. Additionally, an export limiting device designed specifically for V2G was designed, witness tested and installed at a number of customer properties where the DNO had identified network constraints.

Octopus Energy has developed a new tariff to encourage customers to plug in their vehicles as often as possible to charge during off-peak hours and export during times of high system demand. In addition, first of its kind participation in the Electricity System Operator's (ESO) Balancing Mechanism has been successfully tested.

A roadmap to scaling up V2G to a mainstream offering has been developed, leveraging the learnings and achievements of the Powerloop trial as presented in this paper. A number of challenges must be overcome to achieve the goal of wide-scale V2G that fall into the following four broad categories:

- Connection process
- Unlocking value for consumers and the networks
- Consumer uptake
- Technology

The DNO connection process is the first step in the rollout of distributed low carbon technologies such as V2G, which will be key to the decarbonisation of domestic transport. Including V2G into and aligning this technology's rollout with both DNO strategies and local grid flexibility needs is critical to widespread rollout and commercialisation. The main areas where investment and improvement would be most effective in streamlining the rollout of low carbon technologies including V2G are a) the length and requirements of the connection process, b) low-voltage data granularity and availability across the network, and c) the G98 "connect and notify" vs the G99 "apply to connect" limit and need for grid reinforcement in certain regions.

A collaborative effort is required from the key stakeholders to address these challenges, including the following action areas:

- DNOs have a vital role in the adoption of V2G and should work with the ESO, energy suppliers, and the wider energy industry to streamline the connections process.
- This collaboration should compare the value proposition for V2G with Vehicle-to-Home (V2H) and V1G (smart, one-directional charging), to help to build a positive consumer business case.
- Energy suppliers have an important connection with consumers and should use this to increase consumer awareness of V2G and help to make the transition to V2G as painless as possible. Additionally, energy suppliers and charging equipment manufacturers should consider their opportunity to reduce initial investment required for V2G by investigating the potential to provide charging equipment leasing.
- Charging equipment manufacturers should work with automakers to ensure the widespread adoption of charging standards such as ISO 15118-20 and to conduct further research on assessing the implications of bidirectional charging on EV battery life. Moreover, investments in research and development for consumer V2G chargers should be made to help bring down the present high purchase costs for this equipment.

The Opportunity for Vehicle-to-Grid

The Need for Flexibility

Future demand on the electricity network will be significantly impacted by the increasing electrification of heat and transport. The UK has an ambitious target for net zero emissions by 2050 which will see the continued growth in highly variable renewable energy generation. This will result in the increasing importance of system flexibility to balance energy supply and demand while minimising the need to overbuild generation capacity and expand distribution and transmission infrastructure.

Flexibility can be achieved on the supply side by increasing or decreasing the amount of electricity generated. Currently, electricity supply is flexible to meet demand owing to the nature of fossil fuel generators which are not dependent on natural factors such as wind or sun. However, supply side flexibility is not preferable because of this dependence on fossil fuel generators. The increasing proportion of intermittent renewables in the energy mix therefore requires an alternative solution to provide flexibility. Demand side flexibility is generally more cost effective and relies on energy users regulating their consumption or their time of usage in order to match supply.

A Potential Solution

Vehicle-to-grid (V2G) is a demand side solution for this growing need for flexibility and the UK's expanding fleet of EVs (electric vehicles) is a good opportunity to provide this. In contrast to V1G, which is a smart way to manage charging the vehicle to provide grid flexibility, V2G involves the vehicle actively exporting power to the grid at times of high demand. In February 2022, the UK's market share of PEVs (plug-in electric vehicles) reached a record high, exceeding 25% of all new cars sold, which includes an approximate 18% share for BEVs (battery electric vehicles)[1]. The number of EVs on UK roads is expected to continue to increase, driven by the ban on the sale of ICE (internal combustion engine) vehicles planned for 2030, and greater consumer preference for green technology leading to the commitment of several automakers to stop developing and selling ICE vehicles earlier in the decade.

EVs with bidirectional charging capability have the advantage of being cost-effective DERs, requiring minimal additional investment, as their existing under-utilised batteries are already purchased by the vehicle owner.

V2G is an emerging technology that takes advantage of the ability of EVs to store charge in their batteries and discharge power back to the grid during times of high demand. EVs with bidirectional charging capability have the advantage of being cost-effective distributed energy resources, requiring minimal additional investment, and utilising the resource of the existing batteries that are already covered as part of the overall EV lease cost (with no extra cost for V2G services). Imbalances in electricity supply and demand are mitigated by flexibility services which can be provided by EVs with bi-directional charging capability in the future, creating new revenue generation opportunities. In addition, V2G EVs can provide crucial congestion relief for Distribution Network Operators (DNOs) at a distribution level, while also being able to participate in macro system balancing activity. By discharging during peak demand, consumers can significantly reduce their overall energy cost by avoiding import during these periods. The UK's growing fleet of EVs can provide a potentially large supply of flexibility since cars and vans in the UK typically have low utilisation and on average are parked 96% of the time[2]. At scale, V2G can provide a substantial

[1] https://www.smmt.co.uk/vehicle-data/car-registrations/

[2] https://www.racfoundation.org/media-centre/cars-parked-23-hours-a-day

reduction in the need to upgrade power plants and distribution infrastructure, increase the rate of renewable penetration by providing storage and lead to overall power system cost savings.

Recent V2G Projects

Whilst V2G technology is not yet a mainstream commercial offering, a rising number of energy companies, charging companies and automakers, have identified this as a growth option and are developing products.

Project Sciurus

Project Sciurus, led by OVO Energy, was operational during 2020 with over 320 domestic V2G installations in the UK[3]. The key objectives included evaluating the economic potential of V2G and understanding customer behaviour. Amongst their findings, they estimated that the annual revenue potential for each V2G charger was £340, rising to £513 if FFR (Firm Frequency Response) was included. This revenue potential was dependent on having customers with low vehicle utilisation.

Electric Nation Vehicle to Grid

Electric Nation is a current V2G trial led by Western Power Distribution (WPD) that started in May 2021 and will recruit around 100 domestic participants to install V2G chargers. The project will run until mid-2022 and their aims include an evaluation of how V2G benefits and effects the low voltage (LV) electricity network, and policy and commercial recommendations for the roll out of V2G. Project partners include WPD, Crowdcharge, Drive Electric and EA Technology.

EV-elocity

EV-elocity ran from September 2018 to January 2022 with partners including Cenex, CrowdCharge, Leeds and Nottingham City Councils, The University of Nottingham and The University of Warwick. The project involved the installation of 15 bidirectional chargepoints installed across various locations in the UK with the objective of demonstrating V2G in real-world scenarios to gain practical insights into potential technical, customer and commercial benefits. In addition to environmental and cost benefits, a notable finding from this project was that with a blended approach of smart and bidirectional charging can actually improve battery life.

e4Future

e4Future is a V2G project that is being led by Nissan to explore the benefits of V2G for commercial vehicle fleets[4]. Commercial vehicles typically have more predictable daily usage, and the project seeks to gain learnings on operational feasibility for these fleets, the commercial potential and infrastructure requirements. In 2020, 20 V2G chargers were installed at Nissan's Technical Centre in Cranfield and the project is expected to complete in 2022. Project partners include E.On, Imperial College, Newcastle University, UKPN, Northern Powergrid and National Grid.

Notable International Projects

The Parker project in Denmark ran between 2016-2018 and demonstrated renewables-powered V2G, utilising an EV fleet from multiple automakers including Mitsubishi, Nissan, and PSA Groupe[5]. The

[3] https://www.cenex.co.uk/projects-case-studies/sciurus/

[4] https://www.eonenergy.com/v2g.html

[5] https://parker-project.com/

project, led by DTU Elektro (Technical University of Denmark), established V2G's potential for frequency response services and the possibility of commercialising this technology. Other project partners included Enel X, Insero and the Danish utility Frederiksberg Forsyning.

In the USA, the UCSD Invent project took place on the University of California San Diego (UCSD) campus, California, between 2017-2020, led by Nuuve[6]. Partners included Nissan, Mitsubishi Motors, Hitachi, BMW, NREL, PG&E, SDG&E and SUNSPEC Alliance. Using a fleet of over 50 vehicles, the innovation award-winning project validated the benefits of V2G by demonstrating that EV owners can share their batteries when not needed and found that battery degradation due to bidirectional charging was minimal.

Led by FCA (Fiat Chrysler Automobiles – now Stellantis) and ENGIE Eps, the Drosso V2G project in Mirafiori, Italy involves the construction of infrastructure that will be able to interconnect up to 700 electric vehicles. When complete it will be capable of providing ultrafast grid services to the transmission network operator, as well as recharging the vehicles themselves. In addition, the project will be the largest of its kind and the plant will be able to use the EV batteries to provide grid stabilisation services.

Redispatch is a German project run by Transmission system operator TenneT, Nissan and The Mobility House. The project successfully deduced that at home V2G technology would be suitable to stabilise the German power grid, using 10 Nissan Leafs throughout 2018 to 2021. It does so by limiting the wasted renewable electricity produced in the North by storing it in car batteries and by reducing the need for fossil fuel powered plants in the South by taking energy from EVs during peak demand.

[6] https://nuvve.com/projects/ucsd-invent/

The Powerloop Trial

The Powerloop trial is funded by the Department for Business, Energy and Industrial Strategy (BEIS) and the Office for Zero Emission Vehicles (OZEV), with Innovate UK acting as delivery partner. Launched in 2018, it is one of the trials awarded as part of an Innovate UK competition targeting innovation in vehicle-to-grid (V2G) systems through real-world demonstrators. Powerloop offered a bundled proposition, including an EV car lease, bi-directional V2G charger and installation, a V2G time-of-use tariff and an app, to 135 customers. The Powerloop consortium includes key players in the energy industry, spanning energy suppliers, technology companies and specialist consultants (Table 1).

Table 1 PowerLoop Consortium Members

Consortium Member		Project Role
energy saving trust	Energy Saving Trust	Energy Saving Trust (EST) are an organisation committed to the promotion of sustainable energy use and have been analysing the customer experience during the trial to develop a customer best practise for V2G.
Guidehouse	Guidehouse	Guidehouse a global consulting firm providing project advice and analysis over the project. Guidehouse have been engaging with the UK DNOs to gain their insights and leveraging Powerloop learnings to develop a roadmap for the large-scale roll-out of V2G.
octopus electric vehicles	Octopus Electric Vehicles	Octopus Electric Vehicles (OEV) is a UK based Electric Vehicle specialist, and the project lead for Powerloop. They offer a full service on EVs: from expert advice on financing, to maintenance, home-charging installations, specific electric vehicle tariffs, as well as assistance in leasing an electric vehicle.
octopus energy	Octopus Energy	Octopus Energy is a renewable energy and gas supplier funded in 2015 and now operating globally. Octopus Energy is the supplier for all customers on the Powerloop trial, providing them with a 100% green V2G time-of-use tariff.
open energi	Open Energi	Open Energi are providers of an AI-enabled platform to manage V2G and other low carbon technologies and connect them to energy markets. Open Energi provide Powerloop with chargepoint monitoring and provision of the scheduling engine.
UK Power Networks	UKPN	UKPN is the Distribution Network Operator (DNO) supporting the project, developing a streamlined connection process for customers participating in V2G.

Key Trial Focus Areas

The trial was launched with four key objectives, namely to:

1. Gain insights into **customer needs, driving behaviours**, and what **propositions** they are attracted to.
2. Collect data and **collaborate with the local DNO** to understand and improve the process of connecting V2G to the grid, and inform on the **opportunities to provide flexibility services** at a local and national scale.
3. Build an **optimisation and dispatch platform** allowing the charge and discharge to be scheduled, controlled remotely, and aggregated across multiple devices.
4. Develop a **business model that delivers value** to all parties in the value-chain.

As a distributed low carbon technology, V2G is unique in its interaction with the local grid - it is an EV requiring sufficient import headroom to charge; as well as an exporting device (a battery), requiring an approved and safe export connection. As such, the connection request, assessed by the local DNO, has multiple requirements and adds complexity to technology adoption.

Powerloop is focused in the UK Power Networks (UKPN) geographic service area, which has enabled an in-depth focus and collaboration with a single DNO (Distribution Network Operator). In addition, Guidehouse engaged with six UK DNOs (Electricity North West, Northern Powergrid, Scottish & Southern Energy Networks, SP Energy Networks, UK Power Networks, National Grid Electricity Distribution) through individual interviews and working group forums to understand the wider network perspective on residential V2G. While the experience of V2G technology varies between DNOs, several focus areas to enable the mainstream rollout of V2G emerged. These can be categorised into four key themes:

- **The connection process** - the length of assessment and the documentation requirements of the connection process, as well as the G98 “connect and notify” versus the G99 “apply to connect” limit triggering reinforcement needs in some cases.
- **Unlocking value to customers and the network** - understanding where customers can derive value from the technology and the role of time-of-use tariffs and optimisation to enhance that; understanding where the DNO/ESO can derive value and include V2G in their net zero flexibility strategies on both a local and national level to enable the commercialisation of the technology.
- **Customer uptake** – increasing awareness and use of V2G among residential consumers through a positive economic proposition and a smoother customer journey for those transitioning to V2G.
- **Technology** – scaling up the availability of required technology and standards for V2G.

By analysing the main trial findings and engaging with all major UK DNOs, this paper **discusses the challenges and opportunities of domestic V2G and presents a roadmap for how V2G can become a wide-scale future offering in the UK**, taking particular note of the challenges and opportunities perceived by DNOs.

Challenges Facing Residential V2G

As part of the Powerloop project, Guidehouse has engaged with the UK distribution network operators (DNOs) through individual interviews and working group forums. This enables us to understand the network perspective on residential V2G. While the experience of V2G technology varies between DNOs, several key themes emerged.

The six UK DNOs have been engaged with to understand the network perspective on residential V2G.

Flexibility will play a significant role in the future energy system. The uptake of low carbon technologies such as EVs and heat pumps will increase the demand for electricity in the home. For example, the UK Government's ten-point plan aims for 600,000 heat pump installations per year by 2028[7]. If the large numbers of heat pumps and EVs that are forecasted are not managed efficiently, they will cause problems for the low and high voltage networks. DNOs see an opportunity for managing these technologies effectively as electrification increases.

Technologies that enable demand side flexibility, such as V2G, will reduce peak demand on the networks. For example, one DNO expects V2G to play a role offsetting the demand of residential properties. While V2G cannot solve network capacity issues on its own, the DNOs expect it to work in tandem with other solutions such as smart charging. A range of technologies will need to be utilised in offering flexible services.

The four key areas where investment and improvement would be most effective in streamlining the rollout of V2G are:

1. The length and requirements of the connection process.
2. Unlocking value – Maximising the benefits of V2G to the consumer with the development of business models that deliver value to the consumer and the network.
3. Improvements in customer uptake to enable mass rollout in the future.
4. Technology – Supporting and scaling up the required technology and standards for V2G.

The following sections discuss each of these areas in further detail.

The Connection Process

Following consumer sign-up, the DNO connection process is the first step in the rollout of V2G. The current connection process for V2G can be time consuming and is unlikely to be fit for purpose to manage a significant increase in the number of people using this technology, creating a barrier for both the consumer and the DNO. Furthermore, in constrained areas the connection of additional generation above the G98 limit can lead to the need for grid reinforcement, currently payable by the consumer and largely cost-prohibitive. A simpler and faster process is critical to both consumer satisfaction as well as the rate of penetration of this technology.

There are two elements to the connection of V2G:

- **The Electric Vehicle Charge Points (EVCP) application** - this application assesses whether there is sufficient import headroom to charge an EV taking into consideration the maximum

[7] https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title#point-7-greener-buildings

demand of the property and the existing fuse rating. If the maximum demand exceeds the existing fuse rating, the fuse is upgraded by the DNO free of charge up to 100 Amps. If a three-phase supply is needed, this is payable by the customer. The service level is currently 10 days.

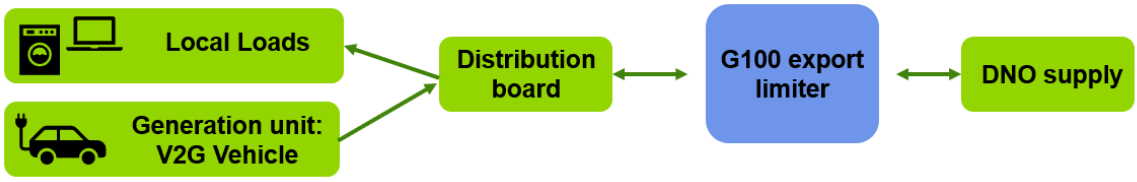
- **The ENA Engineering Recommendation (EREC) G99 or G98** - the grid connection process for the export element is determined by the rated export capability of the charger. Either a G98 or G99 needs to be obtained. In some cases where an export limitation is required by the DNO, a G100 is needed instead. The main differences between the G98 and G99 are:
  - G98 is intended for connections up to 3.68kW. These connections do not need an application before connecting, but require that the DNO is notified within 28 days of the equipment being installed. This process is known as "connect and notify." To connect and notify, the consumer – or, most commonly, an installer on behalf of the customer - completes a G98 Form[8]. Once complete, the form is normally emailed to the DNO for processing. The installer needs to provide the DNO with details of the project, including:
    - Installation Commissioning Confirmation Form
    - Inverter Type Test Certificate
    - Schematic drawing showing details of the generator and phases
  - G99 is intended for connections over 3.68kW per phase and requires a detailed network assessment. The installation cannot go ahead before the DNO has approved the G99, issuing a "No Works Letter." This process is known as "apply to connect." Currently a 45-working day service level is in place for a response to a G99 application. If any reinforcement work is required, or an export limit applied to the connection, these will be outlined as part of the response. As with smaller connections, the installer provides the DNO with details of the project:
    - Completed 'microgeneration connection (50kW or less)' application form
    - Inverter type test certificate
    - Schematic drawing
    - Site plan

[8] ENA G98 guide: https://www.energynetworks.org/assets/images/Resource%20library/G98%20Single%20Premises.pdf

Export Limitation

Related to the grid connection standards is the G100 Export limitation scheme. This is relevant since it enables V2G customers with other generation assets such as solar, or who are in congested areas with a resultant export limit on the property.

An Export Limitation Scheme measures the power at points within the customer's installation and then uses this information to either restrict generation output and/or balance the customers demand in order to prevent the export to the Distribution System from exceeding the agreed export capacity. This enables the vehicle to export at higher power to the home and to the network simultaneously, without exceeding the agreed export limit, for example with a G98 'connect and notify' connection.



In terms of streamlining the connections process, there are two important actions that should be accomplished:

- Acceleration of the rollout of LV network monitoring equipment
- Simplification of connection assessments and DNO installations

LV Network Monitoring

Currently the DNOs do not have sufficient visibility of the low voltage (LV) network, which is inhibiting their ability to maximise the benefit of low carbon technologies, including EVs, V2G and heat pumps. Having a higher level of visibility across the LV network will enable DNOs to anticipate and target areas for network reinforcement and model future demand on the network. In addition, the effective deployment of demand side flexibility requires DNOs to have a high level of detail and granularity on the condition of the network, understanding where the areas of high demand and congestion are. Understanding this in real time requires improved monitoring of the network in order to provide targeted flexibility services maximising network efficiency and keeping costs low.

Data from the Powerloop trial suggests that 15% of G99 applications are rejected due to network constraints. In cases where the G99 is not accepted, the customer can either proceed with grid reinforcement or in cases where there is existing generation in the property that can be switched off, such as solar PV or another V2G vehicle, a G100 can be considered. Currently, network reinforcement above the G98 limit is fully payable by the customer. According to data from the Powerloop trial, the average cost of network reinforcement comes to over £30,000 and none of the trial participants have opted in to pay this cost in order to connect.

In the remaining cases, the pre-existing generation has allowed customers to proceed with the G100 option where an export limiting device is installed as part of the installation. The device is installed with an export limit set by the DNO ensuring that if the export nears the limit, one of the devices is temporarily disabled. As no such device had been designed for a V2G setting before, Octopus

Electric Vehicles invested into the development and testing of a new device which was subsequently witness tested and approved by the DNO.

Some DNOs (quote from interviews) are already making investments into strategic LV monitoring. In addition to these investments, a review of the G98 limit could be considered in order to accelerate the uptake of exporting low carbon technologies like V2G. The level of network reinforcement needed to accommodate the uptake of EVs, heat pumps and V2G will be significant. The current G98 limit (3.68kW) is below the majority of V2G charger export capabilities (6.8kW in the case of Powerloop), meaning that in the cases where network reinforcement is needed, the individual customer is fully liable if they choose to connect. Given that network reinforcement costs are currently cost-prohibitive to the majority of consumers, they are also hindering the rollout of distributed generation such as V2G at scale.

V2G is valuable to grid operators as it can increase the penetration of renewable generation through storage, and provides local level flexibility. If the G98 limit is raised to accommodate for the cost of network reinforcement where it is needed, more of this technology will be rolled out across the network. In addition, areas needing network reinforcement can be identified through the DNO application process, essentially providing a free network mapping opportunity and supporting DNO efforts to increase network visibility. Even though the current proportion of customers triggering network reinforcement is reasonably low (15%), the increasing amount of distributed generation on the network will lead to more constraints and a higher probability of network reinforcement requirements.

In order to increase the visibility of the LV networks there are two immediate actions that can be carried out. Smart meter data is a valuable resource which can be collected using the meters that are already installed in buildings. Network monitoring, if well targeted, can provide valuable data on the state of the network. These two data sources should be combined, along with advanced analytics, to provide state estimation of the high and low voltage networks.

In May 2022, Ofgem completed a consultation on access and forward-looking charges[9]. As part of the review, it was decided that storage is classed as generation and is liable for the payment of reinforcement costs. Though not explicitly mentioned in the review, it is assumed that V2G is classified as storage and therefore also liable.

Speeding up Connection Assessments and Installations

As part of the Powerloop trial, over 180 EVCP G99 application forms were submitted for DNO assessment. All 135 installed bi-directional chargers have fully approved EVCP and G99 acceptance and eight of the participants have G100 approval and witness testing. With these approvals in place, all customers on the trial are able to export to the full capacity of the charger rated at 6.8kW. According to trial data, the average assessment time for a G99 across the cohort was 28 days. Since the approval of the G99 is uncertain and critical for charger installation, the customer cannot proceed with any other aspects of the trial (e.g. credit checks for car lease, car order, etc) before official approval is granted. Due to the long wait time for the G99, the overall average customer journey from sign-up to installation was three months. In cases where additional upgrades are needed (e.g., complex fuse upgrades, looped supply), the customer journey can extend to over six months.

There are multiple strategies to reduce the G99 assessment time and therefore improve the customer journey. Reducing the documentation requirement is an easy method to optimise the assessment time. Feedback provided from the Powerloop trial was a leading factor in the removal of the “Letter of authority” for domestic G99 connections. This change led to a considerable improvement in the speed

[9] https://www.ofgem.gov.uk/publications/access-and-forward-looking-charges-significant-code-review-decision-and-direction

of application by the installer. In addition, Octopus Electric Vehicles introduced the use of a digitalized customer journey making it easy for customers to provide the information needed for the G99 application through a simple questionnaire, including the ability to take pictures of their consumer board and fuse, as well as an automated maximum demand calculation. Collating the information in a centralised database removed a large amount of the manual application inputs, speeding up the overall application process.

In March 2021, UKPN released SmartConnect – a new self-service connections portal for consumers and installers to efficiently connect generation devices, including V2G. The portal simplifies the process and reduces the time normally required to complete the previous manual, paper form[10] and email-based process that was prolonged and difficult for the installers to follow. In addition, further improvements were incorporated into SmartConnect, including a trial for automated fuse rating assessments based on image recognition technology, as well as an automated voltage rise assessment. Enabling an automated voltage rise assessment is a big leap forward for DNOs as this is a complex and time-consuming process requiring a skilled network designer.

SmartConnect Portal

As part of the Powerloop trial, UKPN have developed the SmartConnect portal to decrease the time and hassle of the connections process. By accessing the SmartConnect self-service digital platform the consumer/installer can request a connection. The initial request, network assessment and decision for the network connection are automated as well as providing a platform for gathering the required install information.

SmartConnect gives the consumer an easier, faster and more efficient way to connect their V2G system to the network.

Additional simplifications were introduced in July 2021 when the ENA published their streamlined connection process[11] which included V2G as a separate technology type to EVs and heat pumps. Recognising V2G as a separate technology has reduced the paperwork required to apply and showed the network operator's commitment to the technology.

The installation of V2G equipment is a key area that can be streamlined to both simplify and speed up the DNO connection process. This can be achieved through the provision of effective training for installers coupled with clear and comprehensive installation guides

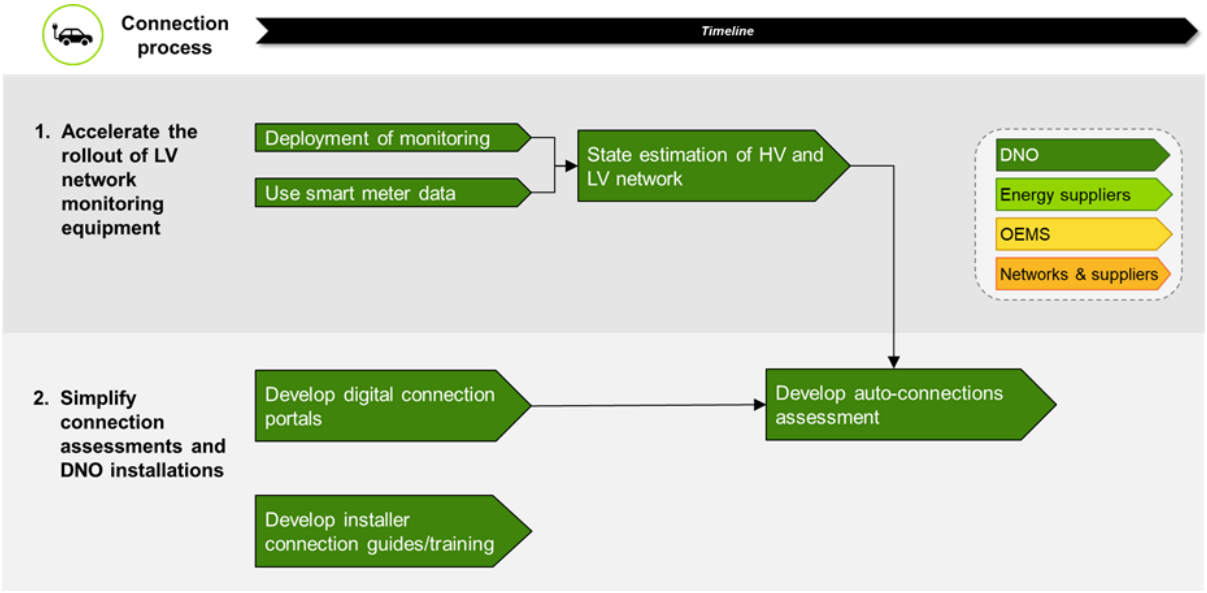
Recommendations for the Connections Process:

1. Increasing low voltage visibility across the network will be essential to the rollout of EVs, heat pumps and V2G. DNOs should increase the deployment of monitoring equipment and utilise smart meter data in order to better understand where network reinforcement is needed and to target local flexibility needs in areas of constraint. Furthermore, the G98 export limit should be reviewed to evaluate whether an increase on this limit can have a positive effect on the rate of V2G rollout if network reinforcement costs are covered by the DNO instead of the individual consumer. Given the value of V2G as a storage and flexibility asset, DNOs should support the rollout of this technology and avoid cost-prohibitive network reinforcement falling on the customer.

[10] https://www.energynetworks.org/assets/images/Resource%20library/G99_Amd%208_01%20(2021).zip

[11] https://www.energynetworks.org/newsroom/slashing-red-tape-on-the-road-to-net-zero

2. Digital connection portals should be developed by DNOs to provide a simple and quicker online process for customers to request a connection. These digital portals will speed up the process and enable the system to cope better with increased demand for connections. Some DNOs are already involving this in their ED2[12] business plans. These digital portals, in combination with improved LV and HV network monitoring will be essential for the development of automatic assessment systems. DNOs should work closely with V2G installers, charger manufacturers, and energy suppliers or third parties offering this service to ensure their feedback from all aspects of the customer journey are incorporated into future connection assessment methodologies. In parallel, the provision of comprehensive training and installation guides for installers will greatly help to simplify and speed up the connection process.



(Source: Guidehouse)

Unlocking Value to Customers and the Network

An appealing economic proposition is required to encourage the widespread adoption of residential V2G. Under the current connection process the majority of customers are able to connect with full export capability. In the case of the Powerloop trial, the charger was rated at 6.8kW import and export.

On the grid operator side (DNO or ESO), local and national flexibility services can be procured through the aggregation and dispatch of V2G chargers. Technologies that enable demand side flexibility, such as V2G, will reduce peak demand on the networks. For example, one DNO expects V2G to play a role in offsetting the demand of residential properties. While V2G cannot solve network capacity issues on its own, the DNOs expect it to work in tandem with other solutions such as smart charging. A range of technologies will need to be utilised in offering flexibility services.

The main challenges for unlocking customer and network value have been identified as:

- Developing near-term LV network forecasting capability

[12] https://www.ofgem.gov.uk/publications/riio-ed2-business-plan-guidance

- Developing customer value propositions
- Understanding and modelling adoption of V2G

Developing Near-Term LV Network Forecasting Capability

As previously discussed, the deployment of demand side flexibility requires DNOs to have a significantly improved ability to monitor the status of their LV networks and forecast when constraints are likely to occur.

One key component of effective flexibility deployment is the ability to send signals to demand and generation assets about the state of the network. This normally happens through price control, with prices increasing at times of high demand and decreasing at times of high generation. Currently, the networks are not in a position to procure flexibility on a short-term (hourly) basis due to the limits in network visibility. This challenge needs to be addressed for residential V2G to be rolled out on a large scale. Short-term load forecasting will increase the visibility of the networks and will ultimately inform the provision of flexibility services. Data from network monitoring and smart meter data will enable more informed and targeted procurement of flexibility services. This short-term load forecasting can then be developed into the near real-time (hourly) flexibility procurement.

Increased visibility and real-time decision making will enable new DNO flexibility products and processes. These should be developed to fit the existing market, with an awareness of future needs and developments.

Developing Customer Value Propositions

Time-of-use tariffs designed to maximise export during peak time can provide a valuable incentive for consumers to plug in and reduce their energy bills, while additionally being rewarded for providing grid flexibility. Octopus Energy has been a leader in this sector with early import smart tariffs such as Octopus Agile and Octopus Go, later shaping their most innovative tariff to date - Intelligent Octopus; as well as export tariffs such as Agile Outgoing. V2G is unique from a tariff perspective as it can benefit from smart charging - like any regular EV - but also has the ability to export, meaning an export element is beneficial for full utilisation of the technology. Intelligent Octopus has both an import and export time-of-use element, with a favourable import rate overnight and an enhanced export rate from 4pm - 7pm. To date, 80% of trial participants have migrated to this tariff. The latest iteration of the tariff aims to optimise the charge and discharge further, moving away from fixed time windows towards a flexible billing methodology where customers are billed according to the service they provide, even if outside of an official price window. This allows vehicle dispatch and billing to be fully aligned with ancillary services and local system flexibility needs without compromising on customer bills.

In addition to time-of-use tariffs aiming to maximise export to the grid, consumer behaviour also plays a part in reducing bills. By discharging stored energy onto the grid, home demand is fully offset meaning that the customer doesn't have to import any energy during peak times when prices are high. Findings from the Powerloop trial suggest that customers often start aligning other energy use (e.g., major appliances such as dishwashers) to the times of export to offset the additional demand with stored cheap renewable energy.

Powerloop is the first domestic V2G trial attempting to dispatch into the ESO balancing mechanism (BM), the largest flexibility market in the UK. Trials were conducted to simulate, prepare for, and test access using an individual vehicle. In addition, a desktop trial was run using post-hoc data, followed by live trials with and without sensitivity to price signals. An API was developed to enable communication between the BM, Kraken Flex (distributed resource management platform) and the

V2G chargers. Successful dispatch in markets such as the BM will demonstrate the feasibility of V2G as a flexibility asset, unlocking value for the grid and consumers.

Discussions should be had between DNOs, the ESO and energy suppliers around the value of flexibility and how the value can be stacked to provide benefit to the consumer. As procurement of flexibility approaches real-time and as new flexibility products become available this will enable meaningful customer value propositions. This is the ultimate end goal if residential V2G is to be a success.

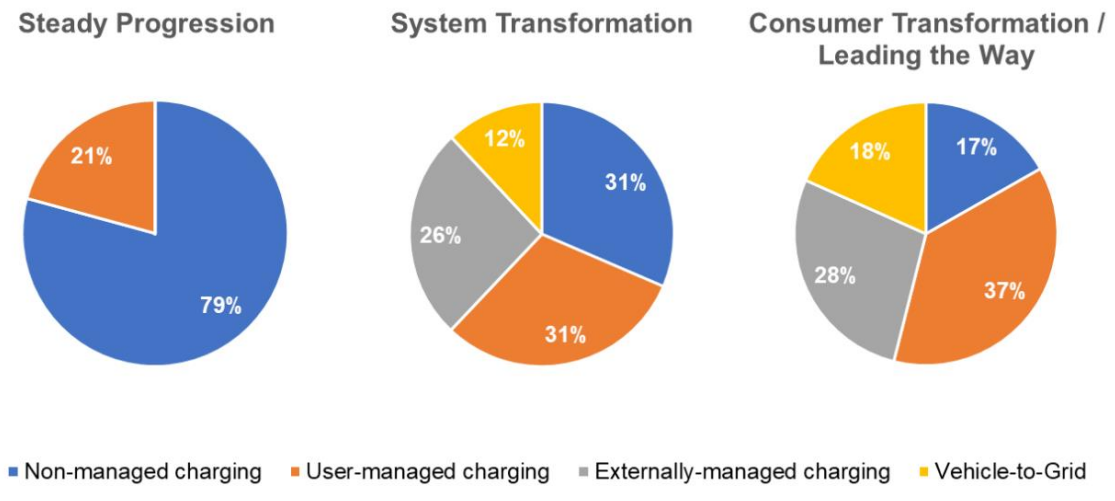
Understanding and Modelling V2G Adoption

Investment planning and effective use of flexibility services requires a good understanding of the level of V2G adoption. This understanding is important both in the short term (next 2-5 years) and also in the longer term as the energy system evolves. It is critical for the DNO as well as ESO to include V2G in both their technology rollout roadmaps (including the connection process) as well as their flexibility procurement strategies.

Aligning the rollout of V2G with both DNO strategies and local grid flexibility needs is critical to commercialisation. While some DNOs are already including predictions of EV and V2G uptake in their business plans, there is not currently a consensus around the expected uptake of V2G or how it will impact the networks. This lack of information or understanding limits the value that V2G can offer to grid flexibility. A particular challenge with understanding and predicting uptake is the effect that possible policy or regulatory changes will have on consumer uptake. Different scenarios should be modelled, and these used to inform business plans and strategies.

Therefore, detailed modelling and analysis of the current and expected uptake of V2G will inform decision makers and influence choices for all stakeholders. When modelling the future uptake of residential V2G it is important to consider the effect of different policy decisions and market signals. In particular, decisions around the connection process and the cost of network upgrades will likely have a significant effect on the volume of V2G adoption and the type of technologies used. The different scenarios should be modelled in detail, including customer preference, technology costs, policy options and possible connection processes.

EV Residential Charging Distribution in 2050



(Source: UKPN, Element Energy[13])

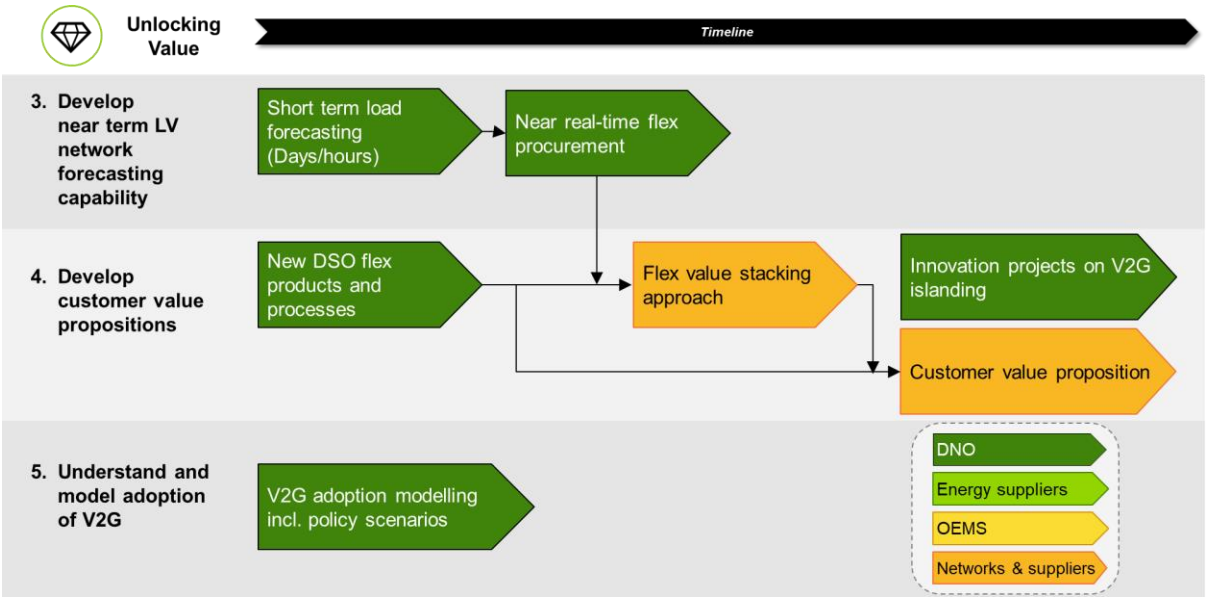
[13] https://media.umbraco.io/uk-power-networks/er1f4esp/2022-dfes-report.pdf

Recommendations for Unlocking Value:

3. Investments should be made by DSOs to develop short-term load forecasting capabilities, supported by data from network monitoring and smart meters to improve network visibility and enable the near real-time procurement of flexibility services.

4. Smart tariffs should be provided for customers, such as import and export time-of-use tariffs which are an effective incentive for consumers to charge their vehicles during peak times. Furthermore, DNOs, ESOs and energy suppliers should evaluate how value stacking can enable a number of grid services to generate multiple revenue streams. DNOs should continue to conduct trials to examine other incentives for the consumer such home islanding which could further enhance the consumer proposition for V2G.

5. Detailed modelling of the consumer uptake of V2G should be carried out by DNOs to support the effective use of flexibility services. Factors including customers preferences, technology costs and policy decisions should be incorporated to evaluate their impact on V2G adoption, and the type of technologies expected to be used to ensure effective investment planning.



(Source: Guidehouse)

Consumer Uptake

Raising the profile of V2G as a technology and educating consumers about its benefits will be critical to mass adoption. Furthermore, this would be strongly supported by technological advancements on the hardware sides lowering costs, as well as wider car choice availability.

The customer journey for V2G is currently complex and often lengthy. According to data from the Powerloop trial, the average customer journey from sign-up to installation of charger and delivery of the car takes three months. At this time in the UK customers are limited in terms of car and charging equipment choice as the industry transitions from CHAdeMO to CCS-enabled bi-directional charging systems. Increasing awareness and understanding of this technology will be key to widespread adoption. Many consumers are unaware of the potential for using the power storage capacity of electric vehicle batteries to shift usage away from peak times and participate in grid flexibility thereby saving money on their domestic energy tariff.

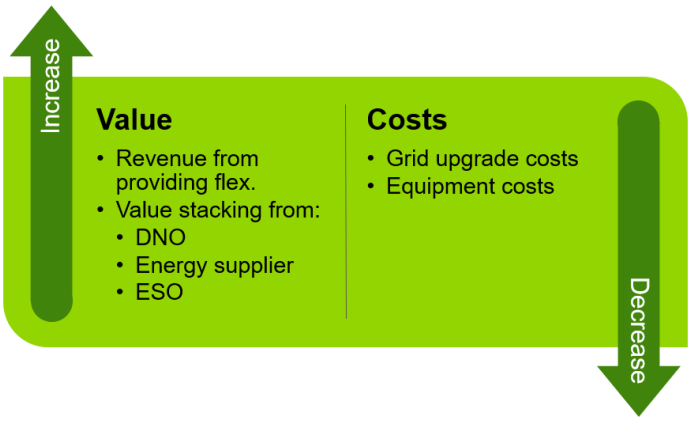
The market for V2G is currently very small, therefore encouraging consumer uptake is essential for residential V2G to be a success. Furthermore, the technology involved is novel, the installation process is disruptive and everyday use of V2G requires behavioural change. Therefore, the following barriers should be addressed in order to encourage the consumer adoption of V2G:

- Building customer awareness
- Reducing the cost of connections
- Reducing the cost of equipment

Building Customer Awareness

Customer awareness should be built through multiple channels. Currently not all owners of EVs are aware of the ability and value of V2G compatible models to export power to the grid and provide flexibility services. Increasing awareness around the opportunity for consumers will support future V2G uptake, especially once more car models are V2G compatible. Trials such as Powerloop are useful in raising awareness about the potential of this technology. In addition, marketing and information campaigns as well as flexibility services targeting V2G can help raise the profile of this technology.

The Powerloop trial offered substantial financial incentives for the consumer to lower the barrier to entry to the trial, including a free V2G charger and fixed monthly cashback for consistent participation in the first part of the trial, followed by the introduction of a V2G time-of-use tariff. Without subsidising large aspects of the customer proposition, large-scale deployment of V2G technologies in a residential setting will rely on an attractive business case, as well as advancement in the charging technology lowering hardware costs. In any case, there is strong potential for a positive customer business case; preliminary data from the Powerloop trial indicates that customers could save around £840 per year on their energy costs. In order for V2G to become scalable, varying customer preferences will need to be taken into account.



Reducing the Cost of Connections

The financial barriers presented by the connections process currently represent one of the most significant barriers to residential V2G. The cost and hassle of the current G99 application process drive the initial investment too high, yielding V2G uneconomical for the consumer.

As the cost of exporting over 3.68kW can be high when reinforcement is triggered, and the disruption is more significant, it may be the case that smaller exports are more economical and efficient for the user. Key factors to consider would be:

- How much is the export limit actually going to limit export? In the long term, will V2G provide flexibility services on a sufficient scale to warrant greater export?
- How much power capacity does the home itself use? As the energy system becomes increasingly electrified the demand of the home will increase. This will draw from the export capacity of the EV. The Powerloop trial is currently collecting data on this topic.

- What is the effect on the network of increased V2G uptake on a street or in a local area?

The relative merits and barriers of each option are complex and will vary depending on scenario. Detailed modelling should be undertaken to understand the effects and benefits of the following three options:

a) Increasing the G98 'connect and notify' threshold (currently 3.68kW).

b) Continuing with the same threshold but removing customer payments incl. reinforcement costs for the larger capacity G99 threshold.

c) Use export limiters to limit export to the grid to 3.68kW.

Reducing the Cost of Equipment

The high cost of V2G charging equipment is a significant barrier to consumer adoption. Furthermore, only a limited number of V2G chargers are available in the UK market, with only the Wallbox Quasar and Indra V2G being both CHAdeMO-compatible and G99 type test approved at present. EV charging equipment suppliers should recognise the opportunity to provide CCS-enabled AC bidirectional chargers – to serve V2G-enabled EVs with onboard bidirectional inverters - and actively pursue certification. Increased research and development and manufacturing V2G chargers at a larger scale, with appropriate certification, would help to drive down costs and provide appealing solutions to customers. Possibilities for novel schemes to reduce the initial barriers to V2G should also be considered. These could include leasing schemes for V2G chargers.

At present, the commercial availability of suitable bidirectional chargers and upfront investment required for consumers wishing to participate in V2G outside of subsidised trials is considerable. In the UK there are no domestic CHAdeMO bidirectional EV chargers available to purchase. Based on prices of trial units, these are currently significantly more expensive than conventional EV chargers, typically a tenth of that cost.

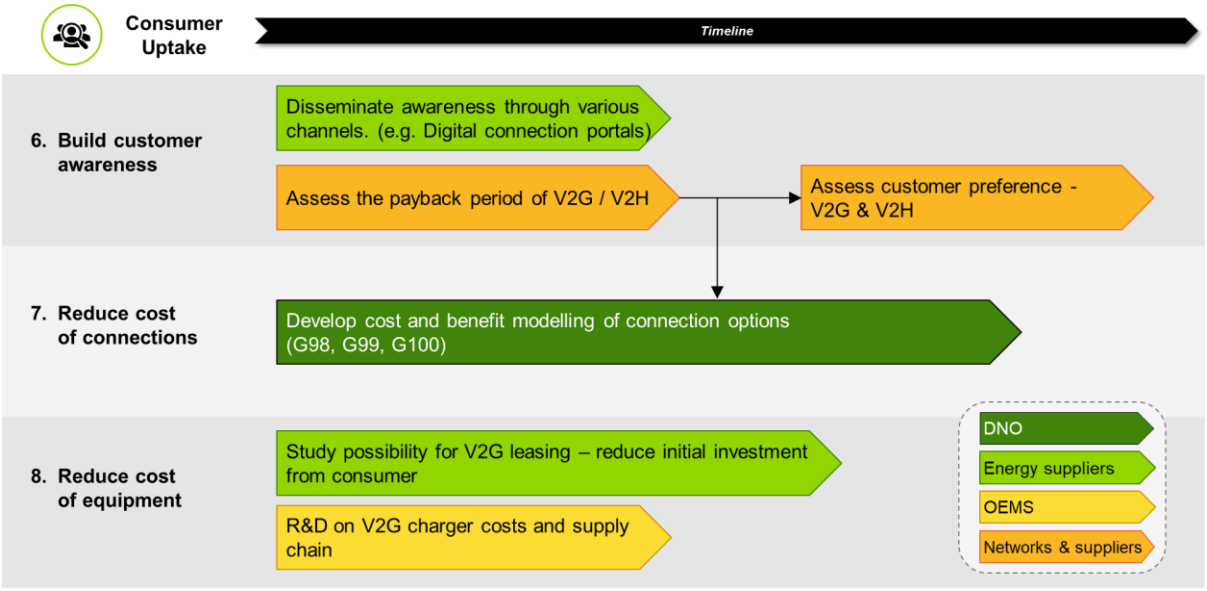
It is necessary for the customer to realise the benefits to themselves and to the grid for providing flexibility. Where the operators such as the ESO and DNOs, and energy suppliers benefit from flexibility on the network, these benefits need to be passed on to the consumer for providing the benefit. Providing a coherent and valuable proposition to the consumer is currently a challenge that will need to be addressed.

Consumer Uptake Recommendations:

6. Energy suppliers should actively work on raising the profile of V2G and educating their customers about its benefits. This should include informing consumers about smart tariffs favourable for bidirectional charging, that will encourage their participation in V2G schemes. In parallel to raising consumer awareness, the networks should investigate the payback period for V2G and V2H for consumers and V2G providers. The outputs of this analysis would enable a study on the potential demand and consumer preferences for V2H which would further support the potential demand bidirectional charging.

7. Detailed modelling should be performed by DSOs to identify opportunities to bring down the cost of V2G connections for consumers. The connection cost for V2G can be a significant up-front investment and network companies should evaluate the potential benefits of permitting consumers to export over 3.68kW without requiring a costly G99 connection. Studies should be conducted to assess the impact of the current export limit and the potential for V2G to provide greater flexibility services by raising this limit.

8. Charging equipment manufacturers should scale up their development of bidirectional chargers to help bring down purchase prices, which are a significant component of the initial investment required from consumers. Additionally, certification for use in the UK is required for a wider range of V2G charging equipment, to provide consumers with a greater number of options. Networks, suppliers and energy companies should examine the provision of favourable financing schemes, such as leasing V2G charging equipment to consumers to further help reduce initial investments.



(Source: Guidehouse)

Technology

Giving the consumer choice of vehicle and other hardware is important, as is ease of use and control over charging schemes. There are some key areas in which technology advancements have been holding back the deployment of V2G:

- Standardizing V2G technologies
- Increasing availability of V2G technologies
- Providing reassurances around battery degradation

Technology Standardisation

The standardisation of technology to support V2G has been recognised as a barrier by stakeholders including DNOs. However, ISO 15118-20, the standard that enables V2G capability, is currently becoming established and is gaining traction. This standard provides the two-way data exchange between the vehicle, charging system and grid that is required to quickly identify and authenticate the vehicle, provide automated billing, enable load management, and offer digital certification for enhanced security. In February 2022, the California Energy Commission (CEC) recommended the adoption of ISO 15118-20 to support the expansion of V2G and the standard was officially published in April 2022. This is the standard behind Combined Charging System (CCS) which will enable V2H, V2B, V2G alongside additional charging methodologies such as wireless for a variety of EVs.

Having this standard in palace provides vehicle and charger manufacturers with the template needed to bring V2G to future car models and chargers, learning from the CHAdeMO experience which has

enabled V2G to date. As the technology moves to CCS-enabled systems – with a split between EVs with and without onboard bi-directional inverters - and the market grows, it is expected that new entrant charger manufacturers will increase the variety and supply of V2G compatible chargers. The simpler design of AC bi-directional chargers could help bring costs down to levels comparable to current uni-directional chargers. Similarly, the cost of CCS-compatible DC bi-directional chargers should also be lower than CHAdeMO chargers through economies of scale of manufacture.

New bi-directional charger products will require type-testing and certifications. Currently there are no AC bi-directional chargers that are type-tested for connection to the UK networks.

Increasing Availability of V2G Capable EVs

At time of writing the only fully V2G capable EV available to buy or lease new in the UK market is the Nissan Leaf, which uses the CHAdeMO charging standard. This limits customer vehicle choice, especially with the increasing range of BEVs now available in most vehicle segments. Vehicles enabled with CCS and capable of V2G will soon be available to customers at scale. Near-market examples include Hyundai conducting large scale trials in Utrecht with their Ioniq5 model, Volkswagen announcing their plans to support V2G with vehicles on their MEB (Modularer E-Antriebs-Baukasten/Modular electric-drive toolkit) platform, Volvo's forthcoming V2G-compatible EX90 and Ford's F150 Lightning pick-up truck already being V2G ready (for the North American market).

As the market develops and competition increases, the original vehicle manufacturers (OEMS) will drive improvements in EV and battery technologies. This will support solutions to the challenges addressed previously under consumer uptake, as V2G-enabled vehicles are manufactured and available at scale. Improvements in EV specific and battery technology will lower costs for consumers and also bring more EVs into play for V2G. Increased publicity from OEMs will also promote V2G and improve consumer awareness.

Providing Reassurances Around Battery Degradation

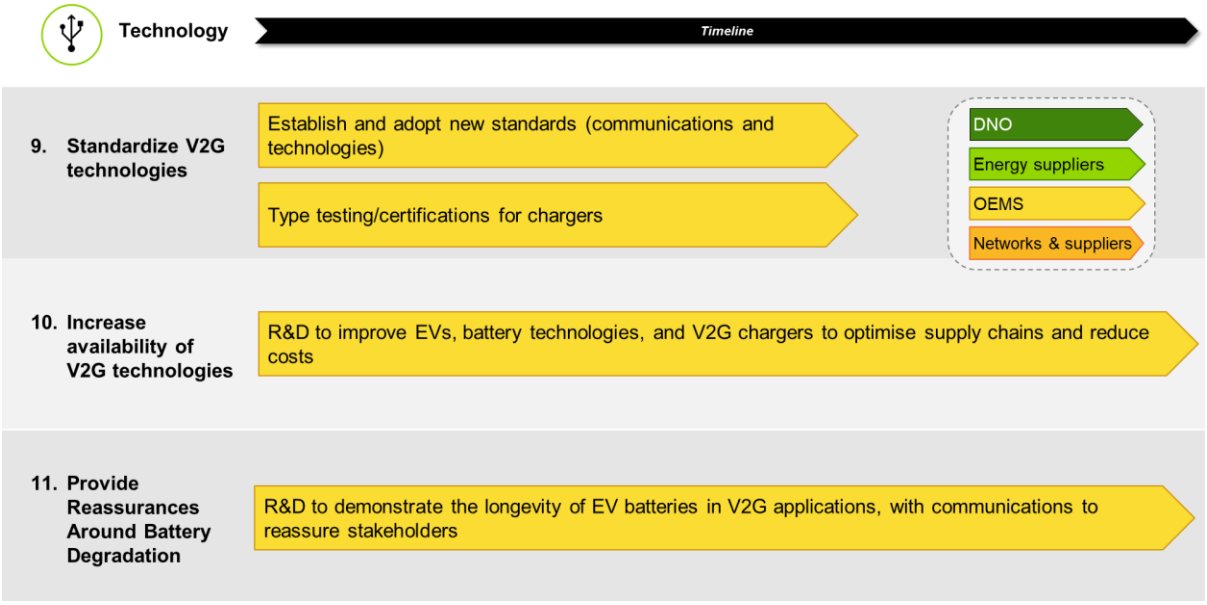
There has been a lack of good understanding and agreement around the effect of bidirectional flow on the lifespan of EV batteries. This is thought to be one of the main contributing factors behind the low number of automakers currently supporting bidirectional charging. However, a recent V2G project, USCD Invent, did not find this to be a significant issue. Furthermore, as mentioned earlier, the EV-elocity project found that a combined approach with both bidirectional and smart charging can actually improve battery life.

Technology Recommendations:

9. Manufacturers of EVs and charging equipment should strengthen their collaboration efforts to establish technical standards that will help accelerate the development and rollout of V2G. Recent developments have been promising, with the progress of ISO 15118, though it is important that manufacturers adopt this standard to ensure the compatibility of cars, chargers and payment systems. As previously mentioned, relevant certification of bidirectional charging is essential for the rollout of V2G in the UK and other markets.

10. Automotive OEMs should include V2G compatibility in their product development plans for future EVs to increase the supply and variety of models available to consumers. Furthermore, they should ensure a greater number of V2G-ready CCS EVs come to market. Likewise, charging equipment manufacturers should support the scale-up of V2G by increasing the supply of bidirectional chargers. The increased availability of V2G compatible vehicles and chargers will help reduce costs to the consumer and drive the adoption of V2G.

11. Manufacturers of EVs, EV batteries and charging equipment should conduct further R&D to demonstrate the impact of bidirectional charging on the life and performance of vehicle batteries. While recent projects have found that there is no negative impact - and even an improvement on battery life, further testing would greatly help assure stakeholders and consumers and provide further confidence in the continued development of V2G.



(Source: Guidehouse)

Addressing These Challenges

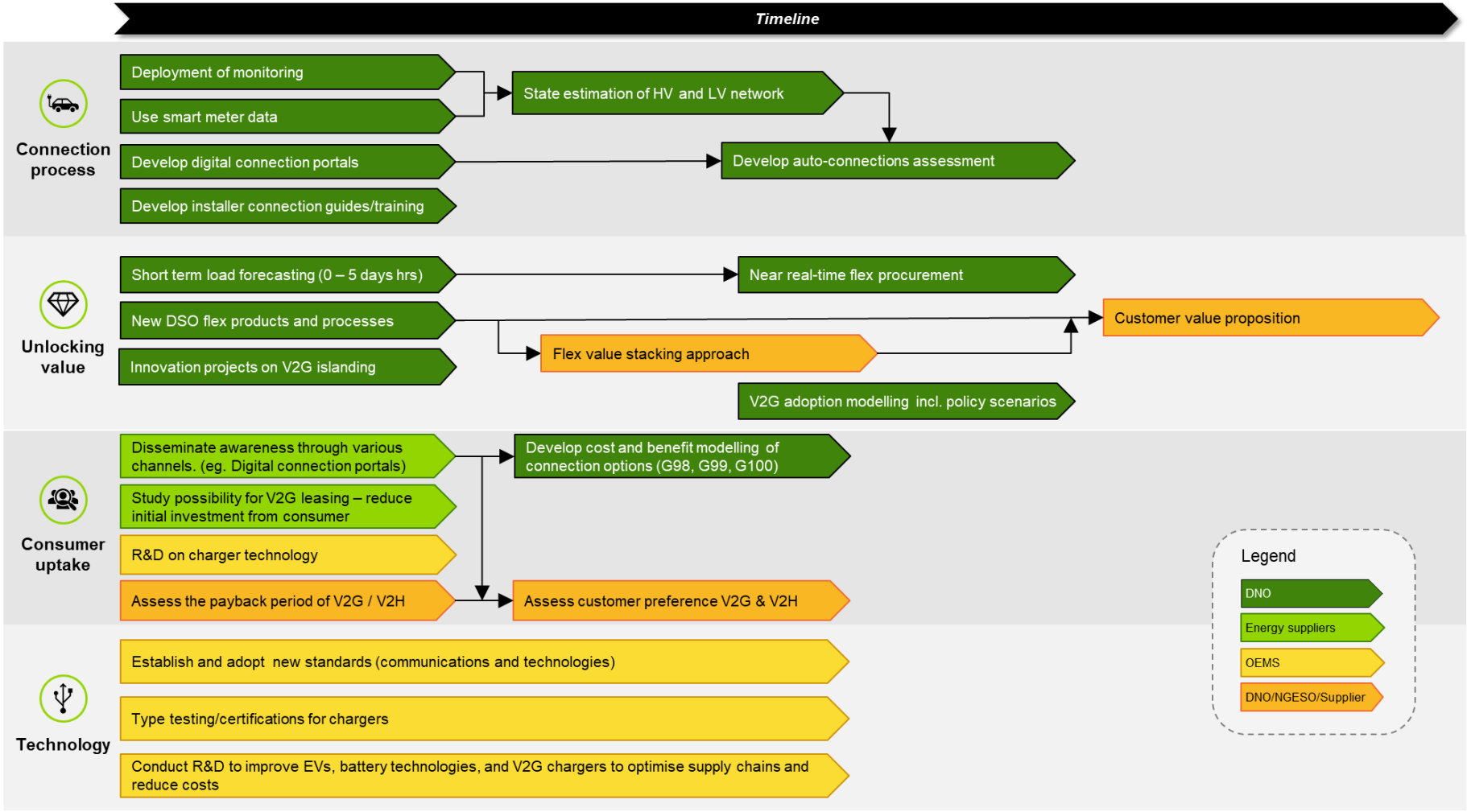
The challenges facing V2G require action from the key stakeholders that include:

- Distribution Network Operators
- Energy Suppliers
- Charging Equipment Manufacturers
- Electricity System Operators

A roadmap has been developed identifying the actions that each of these stakeholders can take to address the challenges facing V2G. While each action is attributed to particular stakeholders, it is likely that every action will require strong engagement between stakeholders.

The following section provides an overview of the roadmap for realising residential V2G in the UK.

Roadmap for Residential V2G



(Source: Guidehouse)

Recommendations and Conclusion

The roadmap has highlighted the challenges facing widespread residential V2G roll out in the UK. While many of these actions have very clear responsible stakeholders, we are able to recommend broad actions for further work:

Recommendations for DNOs

Area		Action
	**1.**	Work with the ESO and energy suppliers to streamline and improve the connections process. Complete value studies to understand the impact on the DNO and the consumer of different connection options.
	**2.**	Work with the ESO and energy suppliers to determine options for value stacking for providing flexibility and build a strong business case for the consumer.
	**3.**	DNOs and ESOs should incorporate V2G into their planning and business strategy, and further examine the potential for V2G to provide flexibility services.
	**4.**	Develop a strategy for network data collection and monitoring. Include smart metering and other current data collection sources.
	**5.**	Develop auto-connections assessment processes and achieve approval from relevant regulators.

Recommendations for Energy Suppliers

Area		Action
	**1.**	In collaboration with DNOs and the ESO, calculate options for value stacking and build the business case for consumers.
	**2.**	Assess consumer preferences around the value proposition for V2G vs V2H vs V1G.
	**3.**	Engage with consumers to increase awareness for the opportunity and incentives for residential V2G.

Recommendations for the Wider Energy Industry

Area		Action
	**1.**	Investigate the value to the sector, in particular the networks, of widespread V2G or V2H.
	**2.**	Initiate discussions between DNOs, ESO and energy suppliers about the connections process. Complete value studies to assess the optimal solution for the connections process.

Recommendations for Charging Equipment Manufacturers

Area		Action
	**1.**	Engage with vehicle manufacturers to standardise the key technologies for EVs and bidirectional chargers.
	**2.**	Increase research and development efforts to improve charging technology and increase availability of equipment for consumers.
	**3.**	Collaborate with vehicle OEMs to optimise bidirectional charging to maximally benefit EV batteries.

Recommendations for Vehicle Manufacturers

Area		Action
	**1.**	Engage with EV charging equipment manufacturers to standardise technologies for EVs and bidirectional chargers.
	**2.**	Conduct further research to deepen the understanding of V2G's effect on battery life and share recommendations with charging equipment manufacturers.
	**3.**	Incorporate V2G compatibility as standard for future EVs to provide consumers with increased choice and availability, and to stimulate market demand.

Conclusion

These recommendations highlight the need for strong coordination across the industry. Challenges specific to particular stakeholders have implications for other stakeholders and processes. Efficient roll-out of V2G technology will require coordinated solutions to address the challenges outlined in this document. The strong inter-dependencies between different facets of the V2G system mean that delay or insufficient action in one area has the potential to prevent or impede the development of residential

Acronym and Abbreviation List

API	Application Programming Interface
BEV	Battery Electric Vehicle
CCS	Combined Charging System
CHAdeMO	CHArge de MOve
DNO	Distribution Network Operator
ED2	Electricity Distribution 2
ENA	Energy Networks Association
ESO	Electricity System Operator
EV	Electric Vehicle
FFR	Firm Frequency Response
ICE	Internal Combustion Engine
LV	Low Voltage
OEM	Original Equipment Manufacturer
OEV	Octopus Electric Vehicles
Ofgem	Office of Gas and Electricity Markets
OZEV	Office for Zero Emission Vehicles
PEV	Plug-in Electric Vehicle
UKPN	UK Power Networks
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home