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Developing the opportunity for V2X bidirectional charging in the UK

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Executive Summary

Bidirectional charging can offer an important source of energy flexibility to help efficiently integrate electric vehicles (EVs) with the electricity system. Enabling intelligent and automated 'smart', bidirectional charging at suitable locations will deliver benefits for climate, the electricity grid and consumers; the electricity system costs are reduced lowering prices for everyone; the motorist saves money from their energy costs, or is rewarded for sharing energy, and the electricity powering the EVs is cleaner and greener. The potential of this technology in the UK is being developed through innovation programmes and policies to develop a smart and flexible energy system. The UK Government funded a Vehicle-to-Grid (V2G) programme between 2017 and 2022 which included over 650 V2G chargepoints being installed across the country. Subsequently, in 2022, the UK Government launched a Vehicle-to-Everything (V2X) innovation programme to address barriers to integrating EVs with other smart technologies and building needs. These programmes provide opportunity for iterative learning to better identify the technical, system, and behavioural barriers to address in the pursuit of the widespread rollout of V2X charging. This paper summarises key policies, strategies, and the objectives and learnings from the innovation programmes.

Keywords: infrastructure; load management; market development; smart charging; V2G (vehicle to grid)

1 Introduction

The UK Government has consistently been a frontrunner in developing climate policy and implementing solutions to the challenge posed by climate change. The UK set the pace by introducing its 2008 Climate Change Act which placed a duty on the government to reduce national greenhouse gas emissions by 80% by 2050 from a base year of 1990. In 2019, the UK became the first major economy to sign into law a net zero emissions target[1]. Government published its Net Zero Strategy in October 2021[2] setting out the UK's critical path to achieving its target. This overarching strategy detailed on a sectoral basis the underpinning approaches and resourcing to meet the collective ambition.

The electrification of power generation, heavy industry, heating, and transportation is critical to realising emissions targets. Government committed to the decarbonisation of the electricity grid by 2035[3] with the rollout of low carbon and renewable technologies and the enhanced use of flexibility services to replace fossil fuel power generation. The transition to a fully decarbonised electricity system reduces dependence on imported oil and gas to deliver clean, affordable, secure power. The sale of new internal combustion engine cars and vans will be banned from 2030, with the ban extending to new hybrid cars and vans in 2035[4]. Alongside policies to increase the uptake of electric vehicles (EVs), government is supporting the ambition of at least 600,000 heat pump installations per year by 2028[5].

Switching these to electricity means the demand for electricity in the UK is forecast to more than double between 2020 and 2050[6]. Such growth in demand necessitates substantial reinforcement of the UK's electricity grid. To make most efficient use of its infrastructure, government is investing in flexibility services to reduce generation capacity requirements, and minimising costs of grid reinforcement estimated at savings of up to £10 billion per year[7]. Smart energy systems and changes to the way in which energy is generated, used and stored all contribute to these avoided costs. System flexibility is being delivered through: legislation placing smart charging as the default option in domestic and workplace charging locations; government funding for V2X programmes which has been available in every year since 2018; and the government's wider ambitions which were announced in its January 2023 Electric Vehicle Smart Charging Action Plan[8].

Whilst EVs pose a challenge to the electricity system in meeting their growing energy demands, they also form part of the solution. EVs have the potential to provide significant demand side response (changing the timing of energy demand) and energy storage in response to electricity system needs. For example, EVs will charge at times when demand is low (typically overnight) or at times when there is plentiful renewable electricity generation. Bidirectional smart charging technologies enable EV batteries to act as storage, so that energy from the vehicle battery can be used to power other things when energy system prices are high. Energy may be exported to a home, a building, or the grid (Vehicle-to-Home/-Building/-Grid), as displayed in Figure 1 below. The term "Vehicle-to-X energy" (V2X energy) is used to describe all these propositions.

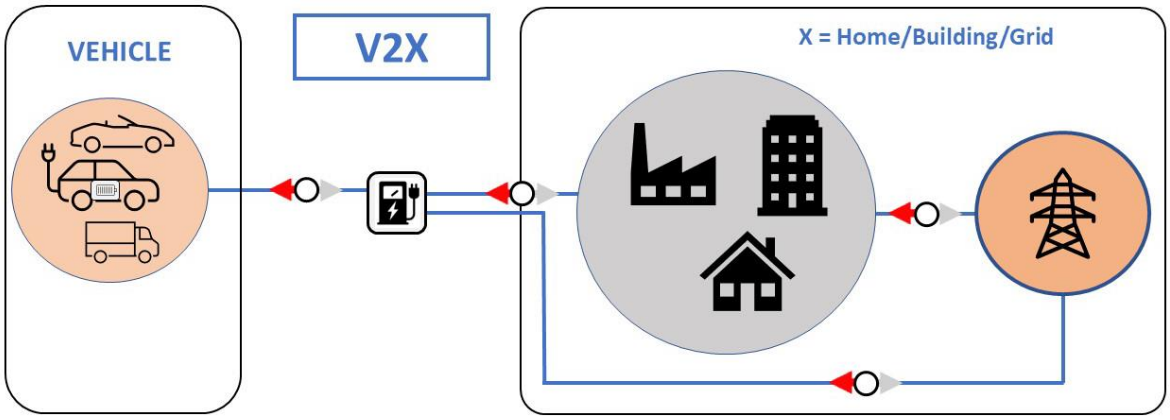

Figure 1: Schematic of V2X services

This paper sets out the opportunity for bidirectional charging technologies in the UK, and the potential barriers that could prevent delivering on those benefits. It then describes two UK government backed innovation programmes, with a summary of the goods and services developed through that work, and the insights that have helped industry and policy formation. Lastly, it maps out the course to maximising the energy storage potential from EVs.

2 Opportunity for energy storage from electric vehicles

Forecasting V2X capacity is challenging as it is highly dependent on technology, energy system development, and consumer behaviour. However, there is a significant technical potential from using EV batteries which could provide an estimated 1500GWh of storage capacity by 2035[8].

It is estimated that if every battery electric vehicle with domestic off-street parking across Great Britain was capable of exporting power it could provide a potential capacity of 60GW in 2035; for context, peak demand in 2035 is expected to rise to approximately 90-105GW[9]. In reality, it is unlikely that the full technical potential will be realised as not all vehicles are likely to be discharging at the same time. Great Britain's transmission system operator, National Grid Electricity System Operator, estimates V2G services could provide as much as 39.3GW of flexible capacity under its most ambitious scenario[9].

The UK Government's ambition for energy sharing from electric cars and vans is that:

- By 2025, innovation projects and technology scale-up will have reduced barriers to entry for consumers and V2X will become more commercially viable. A greater number of V2X-compatible vehicles, increasingly affordable chargepoints, and appropriate tariffs and business models providing revenue opportunities to consumers will be available. Vehicle-to-Home and Vehicle-to-Building technology will be an attractive prospect with 'behind-the-meter' energy optimisation and time-of-use tariffs. Vehicle-to-Grid will increasingly compete in the markets and services of the energy system.
- By 2035, all new cars and vans will be zero emissions at the tailpipe and a significant proportion of these are expected to be V2X-capable. In a zero-carbon power system, these vehicles will provide significant amounts of bidirectional flexibility both behind-the-meter and at local and national levels. Domestic and business consumers participating in V2X will plug in every time they are parked at suitable locations, allowing their car battery to discharge, saving on their energy bills, and potentially earning money, while helping to decarbonise the energy system. The car battery will charge at optimal times during the parked period, enabling the driver to return to their vehicle and begin their next journey with the required charge, while also protecting the battery life.

2.1 Stakeholder views on the scale of opportunity

Government published an open call for evidence[10] on V2X energy technologies in 2021 on the back of the insights gathered from the Vehicle-to-Grid innovation programme (see Section 3). The call for evidence was to gather stakeholder feedback on the perceived role of bidirectional charging technology in the energy system, the barriers to its participation in the system, and the role government has in realising its potential. A total of 50 responses were received from stakeholders across energy and transport sectors. A summary response of feedback received was published January 2023[10].

Stakeholders recognised the opportunities offered through V2X energy technologies and were invested in its development and future role within the energy system. Bidirectional charging was widely recognised as a form of energy system flexibility offering both a source of revenue to businesses and cost reductions for consumers.

Whilst there was a degree of uncertainty surrounding the pace of V2X energy rollout, respondents typically viewed behind-the-meter services coming to market sooner than V2G services, reflecting their simpler underpinning technological requirements over the greater technological requirements in connection back to the grid through aggregation services, for example.

No clear consensus in charging protocols and the location of the bidirectional conversion was prevalent, whether through on-vehicle ac V2X technology, or via the chargepoint and dc V2X technology (both CHAdeMO and CCS).

2.2 Stakeholder views on the potential barriers

Barriers identified can be split across three broad categories: technology, system, and information. Technology barriers focused on the currently limited market of V2X-capable EVs, the price difference between unidirectional chargepoints and bidirectional chargepoints, and the need for fair competition between V2X services and other demand side response propositions. As the automotive industry produces additional V2X-capable EVs and more bidirectional chargepoints come to market, greater product choice will improve the proposition to consumers, meanwhile reducing cost barriers will enhance economic incentives. Business activity and consumer adoption of V2X energy technologies are expected to grow as a consequence of these enhanced incentives. The potential impact of energy sharing on the battery health is often cited by consumers, so further evidence gathering and consumer engagement is required by industry in this area. Cyber security considerations and communication methods between EVs, chargepoints and other

Energy Smart Appliances (ESAs) have been, and continue to be, addressed by government through regulation and stakeholder consultation. The objective is to ensure adequate protections are in place for consumers and for ESAs to retain interoperability within wider smart systems.

System barriers identified included market design and how its design contributes toward flexibility services. The energy regulator, Ofgem, and distribution network operators (DNOs) will need to ensure market design rewards flexibility and allows for equal competition between differing sources of flexibility, including V2X EV charging. Government's Review of Electricity Market Arrangements (REMA)[11] will identify and implement reforms to drive investment and efficient operation in the electricity market. Further systems barriers identified include the grid connection process, managed by DNOs, and ensuring that these connections are completed in a timely, cost effective manner with minimal locational variation.

Government was identified by stakeholders as having a role in addressing information barriers and providing a trusted source of information to act as a reference for parties interested in V2X. Improved consumer uptake will be dependent on consumer confidence. This will be strengthened through further development of the evidence base on battery health and warranty interactions, and through building the financial incentives of V2X technologies. Industry similarly has its role in developing V2X systems which are well-designed and simple to use, thereby incentivising users to plug-in and make their vehicles available for V2X services, all of which should further increase consumer awareness and interest in V2X.

3 Vehicle-to-Grid programme (2017 – 2022)

Launched in 2017, the Vehicle to Grid (V2G) programme was jointly funded by the then Department for Business, Energy and Industrial Strategy (BEIS)[1], and the Department for Transport (DfT)'s Office for Zero Emission Vehicles (OZEV), and was delivered by Innovate UK. This was the first UK supported innovation programme for bidirectional charging.

The V2G programme was one element of BEIS' Energy Innovation Programme[12] which focused on accelerating the commercialisation of innovative clean energy technologies and processes into the 2020s and 2030s. Following a competitive bidding process 20 projects were funded from January 2018 to develop and demonstrate V2G solutions in UK homes and workplaces, and the programme ended in March 2022 following a one year extension due to delays caused by the Covid-19 pandemic.

The objectives of the V2G Programme were to:

- Build confidence in and demonstrate the value of V2G technology to vehicle manufacturers, owners and users with the eventual aim of encouraging significant take-up in the coming 5 to 10 years.
- Learn how to engage EV owners and users and understand their attitudes to different V2G technologies, products and services.
- Demonstrate the technical and commercial potential for EVs to support the electricity system directly to the power grid.

Eight feasibility study projects[13] investigated technology issues, new business models, and consumer engagement challenges, and in parallel four collaborative research projects developed new V2G hardware and software (both on-vehicle and off-vehicle) and standards. The business-led demonstration projects[14] installed over 650 bidirectional V2G chargers for buses and CHAdeMO enabled cars and vans across the UK to test technology in operational conditions. Real-world private EV owners and fleet EV drivers trialed a variety of commercial propositions including fixed and variable tariffs for charging and discharging.

Operational data was collected from the demonstration projects to enable an early-stage study of user behaviour, technical feasibility and commercial benefits for stakeholders in the Vehicle-Grid integration ecosystem. Consequently, UK EV drivers are now providing energy back to the grid from their EV batteries

[1] The Department for Energy Security and Net Zero (DESNZ) was formed in 2023 and is focused on the energy portfolio from the former Department for Business, Energy and Industrial Strategy (BEIS).

when they don't need to use their vehicles for transport, earning revenue and reducing their own recharging costs.

Almost 100 partners from across the transport and energy sectors worked together in the V2G programme including EV manufacturers, energy suppliers, aggregators, grid operators, chargepoint providers and operators, private and local authority fleets, and academics. Partners collaborated to develop new bidirectional charging products and services, overcome grid integration, installation, communication and operational challenges, and to educate consumers about energy systems and the benefits of V2G. The programme has fostered the UK's V2G ecosystem leading to further partnerships in subsequent innovation programmes, and UK designed V2G equipment and flexibility services being introduced to the market.

Innovations included Indra Renewable Technologies developing the first V2G bidirectional charger, designed and manufactured in the UK for use on the Sciurus Vehicle-to-Grid project led by energy supplier OVO Energy. In addition, bidirectional chargers from Wallbox, eNovates and Nichicon were deployed in private homes and fleet depots across the UK, enabling a comparison of both deployment and operational ease, coupled with customer feedback from a variety of consumer use cases. The V2G projects identified important lessons for V2G market development whilst building consumer confidence. They informed the government's 2021 V2X Energy Call For Evidence[10], which in turn informed the current V2X Innovation Programme.

Case study videos for some of the V2G demonstration projects can be found on the Innovate UK website[15]. Further information about each demonstration project can be found on the V2GHub[16] set up by Innovate UK and UK Power Networks to share information about V2G activities around the world.

3.1 V2G programme results

Data collected from bidirectional chargers, EVs, and user surveys conducted by the demonstration projects were used to assess the feasibility of the V2G concept. However, much of the trial period was affected by Covid-19 travel restrictions, and deployment of many V2G sites was delayed, resulting in a smaller dataset than originally intended. Data from 508 V2G chargers located in homes and depots, and more than 500 vehicles operated by private users (domestic) and commercial fleets were subsequently analysed by the UK's Transport Research Laboratory.

3.2 Technical feasibility of V2G

The V2G programme proved the technical feasibility of V2G in UK homes for drivers who can park off-street. In addition, technical solutions were identified for homes with existing renewable generation facilities such as solar PV and heat pumps to alleviate grid operators' concerns. Workplace V2G trials provided technical solutions for depots with electrical supply constraints, whilst helping to alleviate fleet operators' concerns about negative operational impacts and battery life.

In total, approximately 62% of the energy supplied to charge the vehicles during the trial was returned to the grid through V2G services, demonstrating the technology's ability to act as a substantial energy store. The majority of vehicles were plugged-in between 15:00 and 19:00 for the domestic users, and between 13:00 and 16:00 for the commercial fleets. Charging and discharging events took place for 37% of the plugged-in time for the domestic users, and ranged from 25% to 86% for the wide variety of fleet users, indicating spare capacity for greater V2G activity with most trialists.

Figure 2 shows the distribution of starting times for charging and discharging activities in the Powerloop domestic customer project. This reflects Powerloop's commercial proposition, which initially offered a £30 monthly reward to customers available for V2G service between 4-7pm at least 12 times per month. Part way through the trial, two-thirds of customers were moved to an import and export time-of-use tariff, which incentivised them to charge and discharge at certain times of day. This moved the charging peak to midnight and promoted V2G activity during the afternoon/evening peak electricity demand period.

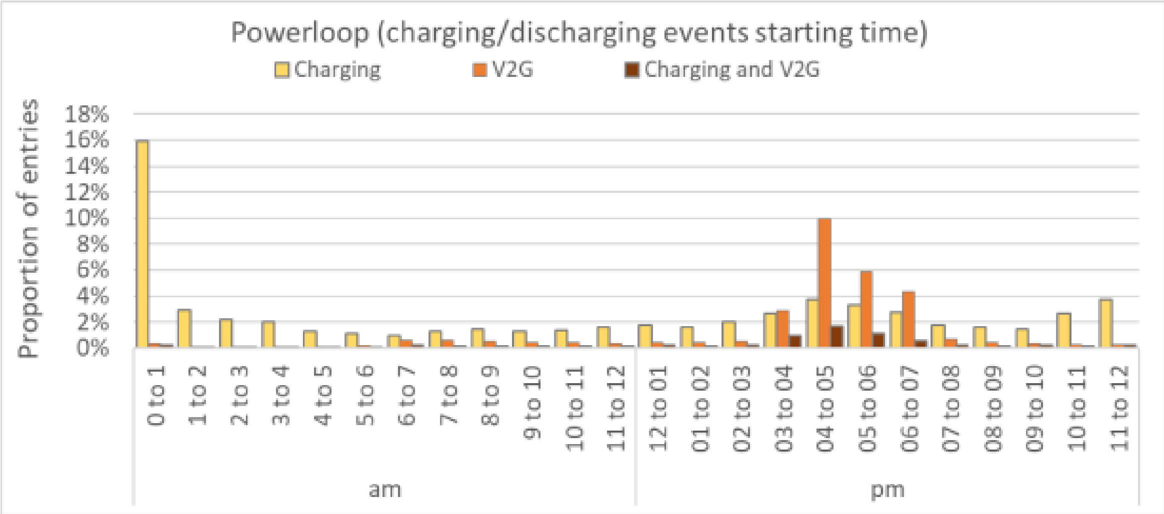

Figure 2: Start times of Powerloop domestic charging and discharging events

Investigation of battery State of Charge (SoC) across the programme found that vehicles were driven away at the end of plug-in sessions with an average SoC of 74%. Fewer than 10% of users chose to override the minimum and maximum SoC targets, implying that they did not consider vehicle range to be constrained by V2G activity.

3.3 Users perceptions of V2G

Driver surveys were undertaken to capture information about their travel patterns and experience of the V2G systems trialed. The private EV drivers undertook the vast majority of charging at home, enabling their V2G chargers to be used for most of their EV electricity requirement. The study concluded that users making frequent, predictable, trips from a single base where they charge represent an optimal use case for V2G, compared with those that charge from multiple locations and undertake a more diverse range of trip distances.

The time an EV was plugged-in and ready to share energy ("plug-in availability") is a key factor in V2G optimisation and tariffs can drive that behaviour. The domestic-focused Sciurus project found that incentives increased plug-in time from under 30% to 57% of the time, and 75% of users reported plugging-in after every trip[17].

Some reliability problems with early-market products clouded users' experience of V2G, particularly amongst fleet users, suggesting a necessary focus for future work. In addition, some users requested more tariff information to understand how to make best use of V2G benefits, so a wider consideration of EV energy flexibility incentives is important to incentivise continued use of V2G.

The majority of drivers surveyed across the programme said they were likely to use V2G again in the future and wanted V2G capability on their next EV. For example, 87% of the domestic Powerloop project customers said they would recommend V2G services and 58% found it easy to integrate into their daily routine, with over 80% of trialists plugged-in between 6pm – 6am on weekdays[18]. Expressions of interest in joining the Powerloop trial reported financial savings as the primary factor, but eventual trialists cited environmental factors as the main reason for taking part.

3.4 V2G and battery degradation

Limited battery State of Health (SoH) data was supplied by the projects, but analysis of the available data provided evidence of a small loss of SoH over the monitoring period, for example 1.8% per year on the Powerloop project. However, no statistically significant increase in the rate of degradation was found before and after V2G activity commenced. Nor was a statistically significant relationship found between battery degradation and V2G use when regression analysis was performed using data from 123 Powerloop vehicles. Further analysis is recommended when a larger dataset is available.

Both domestic and fleet consumers require further reassurance about V2G's risk of accelerating battery degradation, so Warwick Manufacturing Group in the EV-elocity project investigated strategies to protect the battery. They concluded that balancing calendar and cycling ageing produces the strongest all-round battery performance regardless of the intensity of driving[19]. Where the EV is heavily used, a simple time-shifted smart-charging approach best protects the battery. Gentler driving profiles are harder to manage under V2G and pre-conditioning the battery could help. The project's proposed charging strategies could improve battery life from 8.6% to 12.3% for one year's continual operation compared with the reference dumb charging strategy[20].

3.5 Economic viability

Some projects reported economic findings. In 2020, the e4Future project quantified the annual financial V2G opportunity for aggregators of back-to-base commercial EV fleets at between £700 to £1250 per EV, by stacking revenue streams from grid services with cost savings when compared to unmanaged charging regimes [21]. UK electricity network charges have changed since this study and will continue to evolve through the transition to the smart, flexible, net zero system. Therefore, businesses will need to develop new propositions for existing and future network balancing and flexibility products.

By March 2022 the cost of V2G equipment had approximately halved over the programme's lifetime, however the widespread deployment of V2G remained a challenge in the UK marketplace where only CHAdeMO protocol EVs were available to perform V2G. Commercial feasibility was proven for some domestic use cases, typically those with regular long plug-in durations and short trip requirements. Of the twelve different customer archetypes represented in the Sciurus project, the retired professional V2G archetype was found to receive the greatest financial benefit from V2G over smart charging[17]. The 320 customers on the Sciurus trial saved on average £360 per year[22] by using the fixed V2G feed-in tariff offered by OVO Energy, and together participants drove 3 million free miles as a result[23].

V2G equipment prices in the UK remain at least double those of unidirectional smart charging facilities, and grid connection costs were a significant barrier in some locations and user scenarios. Sciurus found that if V2G domestic hardware costs could be reduced to £1000 the payback period could be under five years. Grid connection costs associated with requirements specific to the bidirectional element of chargepoint installations resulted in DNO assessment fees and design fees, as well as costs derived from witnessing commissioning checks. Therefore, the programme concluded that for V2G to become widely commercially viable cost reduction activities must continue, and dc CCS and ac bidirectional charging standards are required to provide greater V2G-enabled EV choice for consumers.

3.6 Electricity system factors

The grid connection process at the start of the demonstration projects detrimentally affected the lead time and consumer experience for domestic V2G installations. From this experience, programme partner UK Power Networks (UKPN) developed a simplified application process for all domestic renewable connections. This new process reduces the application time and cost for both applicants and the Distribution Network Operator (DNOs) and is now rolled out to all UK DNOs by the UK Energy Networks Association (ENA).

Carbon intensity (an estimate of the carbon dioxide equivalent produced by the electricity production) is also an important consideration for the electricity grid. EV-elocity's techno-economic modelling based on commercial users' behaviour concluded that applying a dynamic half-hourly varying V2G tariff reflecting both electricity price and carbon intensity could improve both carbon and cost savings. Optimizing for carbon savings could save 450kg carbon per year [20], demonstrating the environmental and social value to be gained. When optimizing for cost alone, moving from a two-rate tariff to half-hourly could increase financial savings from £100 to £400 per chargepoint annually, whilst also saving around 180kg of carbon.

Users across multiple projects expressed an interest in using their EV's energy to power their own homes or commercial buildings in preference to feeding it back into the grid, setting the scene for the subsequent V2X innovation programme opening up to other .

4 Vehicle-to-X innovation programme (2022 – 2025)

4.1 The Net Zero Innovation Portfolio and Flexibility Innovation Programme

As part of the government's ten-point plan for a Green Industrial Revolution, announced in 2021, a £1bn Net Zero Innovation Portfolio (NZIP)[24] was established to accelerate the commercialisation of low carbon technologies, systems and business models in power, buildings, and industry. The NZIP seeks to bring down the costs of decarbonisation and to stimulate investment and technological advancement, supporting green jobs and regional economic growth in the process. Ten separate priority areas were identified, each with accompanying funding portfolios and complementary sub-programmes seeking to deliver on these ambitions.

The V2X Innovation Programme[25] was launched in 2022 to encourage development of technological and commercial solutions to enable EVs to export energy more widely, for example to homes, buildings and other vehicles as well as to the grid. The V2X Innovation Programme sits within the wider £65M Flexibility Innovation Programme[26], part of the Energy Storage and Flexibility priority area. The V2X Innovation Programme is in receipt of approximately a fifth of that funding and is being delivered over two phases of innovation competitions. Objectives across the various programme and sub-programme levels will deliver on the overarching ambitions of the Ten Point Plan.

4.2 V2X Phase 1

In 2022, 17 collaborative research projects[27] were awarded a total of £3.2million funding from UK government, delivered through the Phase 1 Innovate UK competition. These projects will run until August 2023 and focus on developing new prototype V2X hardware, software, and business models with the aim of reducing entry barriers for EVs to provide energy flexibility services. The variety of projects funded address the primary bidirectional challenges of: cost reduction; customer choice, by adding dc CCS and ac bidirectional charging products and a wider selection of commercial propositions; and widening V2X energy use cases by moving beyond cars and vans to also explore heavy freight and public space opportunities.

4.3 V2X Phase 2

The upcoming Phase 2 competition[28] will seek small scale demonstrations of innovative V2X products and services using real EV drivers in a real-world setting. Up to £9.4 million government funding is available, to be delivered by Innovate UK later this year through a Phase 2 competition.

The aim of this second phase is to test and demonstrate the viability of V2X as a wider source of flexibility beyond V2G for a wider selection of EV users, and to explore its integration with building energy management systems, microgrids, and other flexibility sources. The government funding is provided to accelerate commercialisation of V2X products and services in the UK and to accelerate the adoption of V2X energy solutions by increasing awareness of its feasibility and benefits amongst businesses and consumers.

Projects which are awarded funding will run until March 2025 and will deliver trials using on-road EVs lasting for at least 6 months. Each project will collect data from chargers, vehicles, and users to answer research questions regarding the energy flexibility delivered, the business model trialed, users 'experiences, and remaining barriers to V2X adoption.

5 Future policy development

The UK is a world leader in bidirectional charging energy technologies, with the most diverse range of innovation projects including the largest demonstration of Vehicle-to-Grid (V2G) exporting to the wider energy system. More than 650 bidirectional chargepoints were installed across the country through the V2G

Innovation Programme. However, there is still much to do for bidirectional charging products and services to reach widescale commercial deployment. UK Government's vision is:

- To make bidirectional smart charging the affordable, convenient choice for consumers, increasing consumer confidence (including on battery health) and providing appropriate protections for a positive experience
- To provide the right business landscape for bidirectional smart charging products, regulations, standards and innovation for safe goods and services that give consumers choice, and work for the charging market and energy flexibility
- For an energy system providing tariffs and flexibility services that incentivise bidirectional charging, and cost-effective, efficient grid-connections.

Government will continue to monitor the bidirectional charging sector to identify and address key barriers to unlock its significant potential. Government will intervene where necessary to ensure that consumers and the grid are protected from harm; that could include regulation or standards to facilitate an effective market (for example for interoperability of demand side response, data security, data privacy or grid stability) and innovation investment (for example, access to smart charging infrastructure).

The successful integration of EV charging into the electricity system relies on the collaboration of government and energy, automotive, and charging sectors. All stakeholders must continue to work together to realise the vision of EVs acting not only as a mode of mobility, but also as a critical component of the wider smart energy system, providing resilience and flexibility simultaneously.

Presenter Biography

Dr Josey Wardle is the Innovation Lead for ZEV infrastructure at Innovate UK. She specialises in the infrastructure required to enable zero emission transport, using experience gathered over 13 years working in the EV industry and her recent PhD investigating the future of EV charging. Josey currently manages the EV charging and V2G/V2X programmes of innovation projects funded by UK Government. Innovate UK is part of UK Research and Innovation, a non-departmental public body driving productivity and growth by supporting businesses to realise the potential of new technologies, develop ideas and make them a commercial success. Innovate UK works in all economic sectors, value chains and UK regions to accelerate innovation.

Acknowledgments

Dr Rob Mangan, previously Senior Policy Advisor, EV Smart Energy, Department for Business, Energy and Industrial Strategy

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