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The Feasibility of Employing Wide-Spread Vehicle-To-Grid Technology

Automotive Materials & Sustainability ACHA6012

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1 Introduction

1.1 What is V2G

V2G or "Vehicle-To-Grid" is an engineering solution to an electrical shortage issue nationally and potentially internationally. The theory behind V2G involves the assumption of wide-spread vehicle electrification with the supporting equipment like suitable chargers and battery supply being in full availability. It is suggested that EV use in the UK will increase by 55% in 2032 (CCC, 2021) , which would put the demand on the NG to levels not experienced before. As a result, "700,000 electricity users could suffer from blackouts due to the increased pressure on the grid in 2017" from the increased volume of capita charging their vehicles around the country (UK, 2017). Therefore, the national energy production and delivery system must develop with the ongoing times. Power demands frequently change throughout the day and differ throughout the country due to various epicentres of peak energy requirements.

An example would be Birmingham would require a larger night-time grid supply than Brecon from the difference in population. V2G is seen as a method to help the NG (National Grid) by optimising Bi-Directional charging (ELECTREK, 2020) , allowing EV's to supply the NG with their charge stored and be supplied with charge from the NG. The system works off signals produced (VIRTA, 2021) by the NG supply, demand and energy requirements for the local area at a period, balancing the NG's Power Availability and Demand simultaneously. There are solutions such as V2X "Vehicle-To-Everything", which is a step up from V2G by allowing Vehicle to House or Buildings. However, the focus of this paper will be on V2G.

2 Technical Literature Review

2.1 Current and Future Battery Technology

Barriers are used to store energy for conversion into rotational energy in the form of a motor. For electric/hybrid vehicles, the battery system has many implications on the vehicle's range, performance, and usability. One of the primary areas for investigation regarding batteries is the chemical composition.

2.1.1 Nickel-Based

There are four main nickel-based compounds, including Nickel-Cadmium, Nickel-Iron, Nickel-Metal Hydride and Nickel-Zinc. The primary compound used within the motor industry is Nickel-Metal Hydride, or Ni-MH (Modern Electric, 2005).

Ni-MH batteries possess many desirable attributes for automotive battery application, such as relatively high specific energy and lack of toxicity compared to Ni-Ca. The Ni-MH batteries also bode well in life cycle length and lack of energy density loss over time (Axsen, 2010). The primary drawbacks of Ni-MH batteries are the high volume of hydrogen required to execute the chemical reaction (Torabi, 2020) and high self-discharge tendencies (German, 2004), along with Ni-Ir (Modern Electric, 2005). There have been many applications of Ni-MH batteries within automotive sectors, such as the Prius Iteration 1-5 and the Hybrid Honda Civic (Kurzweil, 2014).

2.1.2 Lithium-Based

The primary compound from Lithium-based batteries is Lithium-Ion due to the increased life expectancy and power density compared to Ni-MH batteries (Tsais, 2013). Li-Ion also provides a cheaper alternative to Ni-MH (Tsais, 2013). Based on a direct comparison from (Turbo Future, 2021), Li-Ion offers much more performance benefits than Ni-MH, whilst Ni-MH has a larger capacity per unit volume, which is ideal for lower powered applications. The Li-Ion battery does have disadvantages, such as the inability to be discharged to 0 percent. Already having a relatively smaller capacity to Ni-MH, there will be a limit where the automotive manufacture doesn't allow the battery to get below a specific charge, resulting in lower range distances. If the battery were to be discharged fully, the efficiency would decrease, and the lifespan will also decrease (Energy, Victron, n.d.). The corresponding depth of discharge will change with the rate of discharge, as seen below.

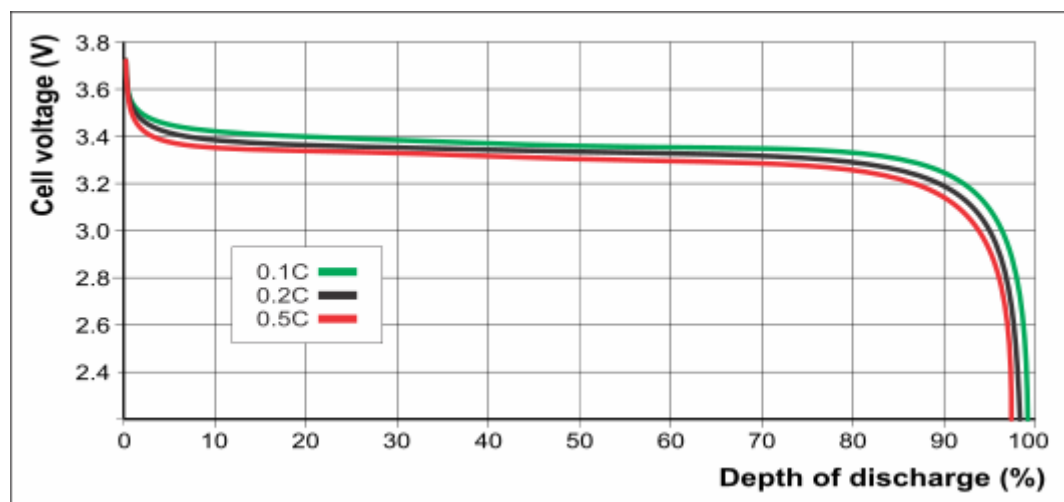


Figure 1-Depth of Discharge v Voltage

(Energy, Victron, n.d.)

Such as ethical issues drawn from the mining required to collect the Lithium. This raises many issues about the sustainability energy debate, as electric vehicles are seen as helping the situation of sustainable energy in the public eye (Center for Welfare, 2019). The previous statement isn't true when considering the operation of EV's outside of the vehicle, as lithium mining is highly adverse to the environment (The Guardian, 2021).

In conclusion, Li-Ion is an excellent source of cheap energy-dense batteries for automotive applications. However, the industry must move on and innovate to different chemical-based batteries or energy solutions as the continued use of Lithium is harmful for the environment. One of the leading pioneers in battery technology is Tesla, and they are still committing their future to Li-Ion and other Lithium-based products after their deal with Panasonic not long ago (MILLER, 2021)

2.1.3 Overall Battery Issues

PEV vehicles have a much more limited lifespan than an ICE vehicle, of around 4-5 years (Chau, 2015) which would lead to a more significant turnover of EV's. This provides a new issue as well as sourcing the chemicals for batteries with the disposal of them. (BBC, 2021) provides a good insight from multiple automotive manufacturers regarding their recycling plan as we advance from old EV's. Renault currently recycles all old whilst Nissan reuse theirs within their factories for automated machines. This is a suitable protocol for now, but Paul Anderson from UoB states that the rate of EV growth is scary, and a recycling plan needs to be created to cope with the larger volume of disposed of batteries in the future. (Morse, 2021) also supports the necessity of an ideally "universal" recycling system, as automotive batteries are from various chemical make-ups, with Li-Ion being the primary make-up for modern technology.

A study by (Fotouhi, 2015) suggests that the range prediction of batteries is a very complex procedure, especially with newer discovered chemical compounds like Lithium-Sulphur. Whilst the Li-Ion technologies have been well-optimised, newer technologies are needed to counter the range issues and range-unpredictability (EV, 2021) where some onboard measurements can be 100% off.

Different Li-ion battery packs manufacturers and EVs in which battery is used [11].

Cathode material types	EVs battery packs manufacturers	EVs developers and EV models	Battery packs usable capacity (kW h)	Approx. range under normal driving conditions (mile)
Lithium Cobalt Oxide (LCO)	Panasonic, Tesla	Tesla-Roadster	56	245
Lithium Manganese Oxide (LMO)	AESC, EnerDel, GS Yuasa, Hitachi, LG Chem, Toshiba	Daimler Benz-Smart EV	16.5	84
		Think-Think EV	23	99.4
		Nissan-Leaf EV	24	105
Lithium Iron Phosphate (LFP)	A123, BYD, GS	BYD-E6	57	249
Lithium Nickle-Manganese-Cobalt Oxide (NMC)	Yuasa, Lishem, Valence	Mitsubishi-iMiEV	16	99.4
	Hitachi, LG Chem, Samsung	BMW-Mini E	35	150

Figure 2-Range values for different EV battery packs

As seen from the above figure, the global consensus is that the range of widely used battery packs are low compared to an equivalent ICE vehicle. However, these range issues are slowly improving (Wallbox, n.d.).

Batteries can be relatively temperature conditional when examining the cyclic charging and discharging abilities of the battery.

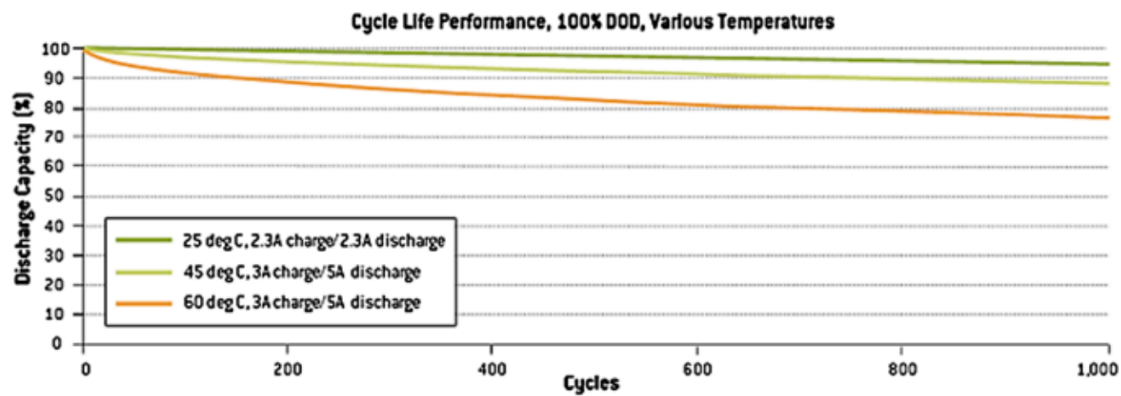


Fig. 15 Cycle life time of Li-Ion Phosphate cell, 2.3 Ah [17]

Figure 3-Cycles v Discharge Capacity

(Nikowitz, 2016)

A direct relationship between decreasing discharge ability and exposure to higher temperature can be drawn from the above figure. Issues can form from this, with more complex temperature controls needed to retain a sustainable temperature. The solution that provides the best cooling performance is controlled water cooling (Nikowitz, 2016), however this adds mass and electrical complexity.

2.1.4 Future Battery Technology

An exciting all silicon solid-state battery has undergone testing with promising results. If this offers a similar performance to Li-Ion, then it could be a much better solution environmentally, as silicon is much more abundant than Lithium (Science Daily, 2021).

2.2 Charging and Bi-Charging Capabilities

Current charging technology is still a relatively new concept to implement. The main concerns with the current state of EV technology are range, cost and the supporting infrastructure.

Table 4. Consumer concerns about electric vehicles in the United States.

Concern	Number of responses	%
Battery range	158	33
Cost	129	27
Charging infrastructure	83	17
Other	58	12
Reliability	47	10
Safety	6	1

Reprinted from [92], Copyright 2012, with permission from Elsevier.

Figure 4-Consumer concerns about electrification

(Sovacool, 2018)

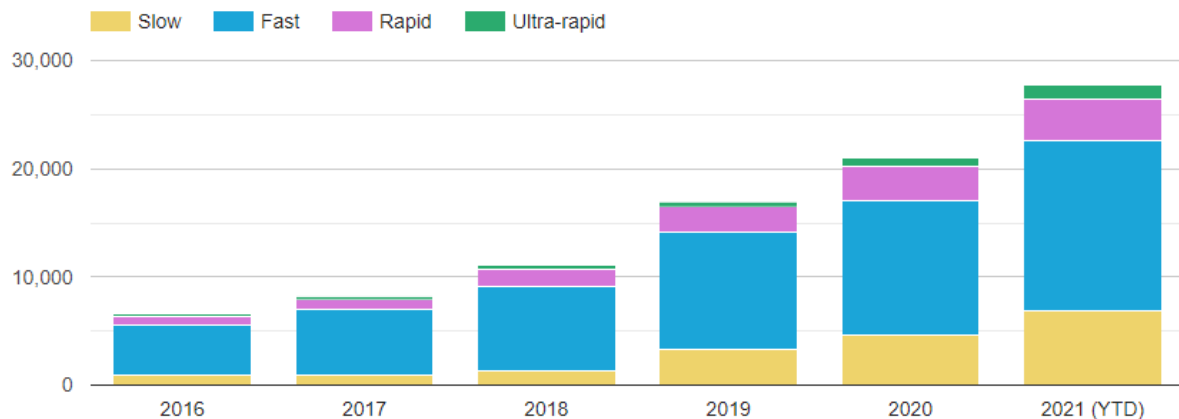
The above figure shows the public concerns from a study in the US with the future of EV's.

A few different factors can be extracted within the charging infrastructure section, such as length of charge, amount of infrastructure, and cost of charge.

2.2.1 Length of Charge

The length of charge correlates to the energy given per unit of time, or power(kW). The charging stations can be ranked by how fast they charge measured in kW.

Number of public charging points by speed (2016-to date)



Total devices: 27729, Updated: 26 November 2021

Figure 5-Number of charging points varied by the speed

(ZapMap, 2021)

The above graph shows the gradual and steady increase in the number of charging stations in the UK since 2016, with the proportion of those being ranked with the speed of charge. Usurprisingly, the most popular chargers are the "fast" chargers, as they provide a good level of power whilst keeping the cost relatively small. Even if a new 22kW charger is over 3000 GBP per unit from (WIA, 2021) being considered a fast charger. Assuming constant price listed on the site of 3,432 GBP, this relates to almost 54 million GBP at time of writing just to purchase all the fast chargers in the UK. This doesn't include cost of installation and maintenance. This is where the worry of cost comes from for users, as the current price of charging stations in the UK is way too high to consider full electrification by the government time frame by 2035 (Euractiv, 2021). With this, the average length of charge for a fast charger stated by the Welsh government is 1.5-5 hours. This depends on the capacity of your battery but assuming 22kW which is the upper echelon of the fast category, compared to 3,960 kilowatt-hours per hour, or 3,960 kilowatts (Autoguide, 2006). This paper is old (2006) and states that the power of chargers is 1.5kW, which has been improved to over 350kW for fast chargers, but a 22kW charger which is seen as "fast" is still 180 times slower than a petrol pump and the 350kW is 11 times slower. This will improve with battery improvements over time; however, this length of charge can lead to issues.

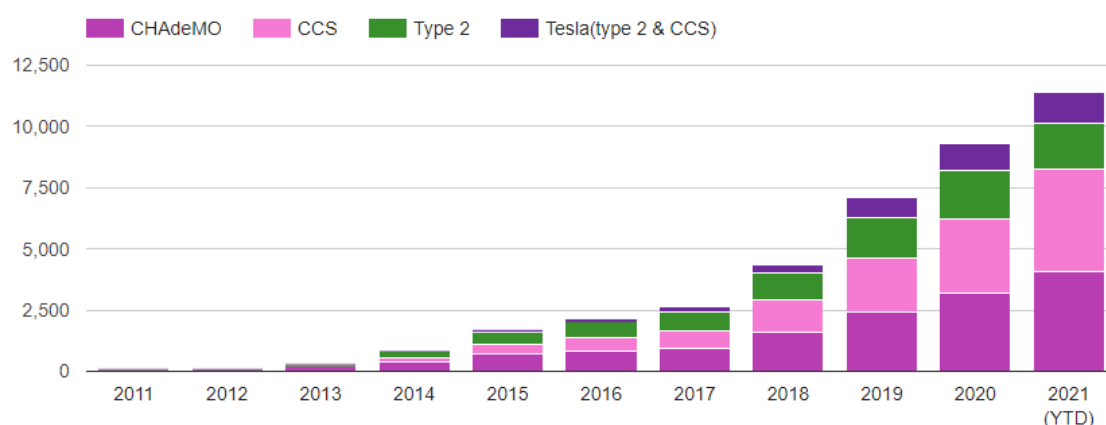
1. Charging your car may become a period you must allocate into your day to avoid being late or missing events which induce an extra level of stress for some people and another level of the impracticality of owning an EV.
2. If the quantity of chargers doesn't correlate to the number of EV's, the usage of the chargers will be almost 24/7, which could lead to faults and maintenance issues or vandalism. This links to possible ethical issues where the people who don't believe in climate change, could protest by cutting the power to people's EV's.

3. The fast chargers require additional maintenance due to the filters and the cables, which need to be extremely well insulated to avoid injury of wear and tear (LAT, 2021)
4. The length of charge could result in a massive backlog of people waiting to charge their vehicle in a public charging station, which makes it highly impractical to people. Its bad enough with petrol stations, which are substantially more powerful. If the government wants to push the increase of EV's to become as popular as ICE, then the length of charge must massively decrease to match or beat petrol for them to justify the change.
5. Specifically, with V2G, the large and varied time required for the vehicle battery to discharge back into the grid provides big issues for batteries and ethical issues.
 - Batteries have different discharge regimes, meaning that a Nickel-Cadmium Battery will have different characteristics to a Li-Ion. If the vehicle is giving energy back, the charger and the overlooking system will need to know what battery type that car is. For example, nickel-based batteries need to be fully discharged before recharging. If this isn't adhered to, the battery life will decrease as well as the different current rate during charge cycles are different for all batteries (Education, n.d.).
 - Many things that happen during the day are unplanned, such as a medical emergency. If the vehicle is connected to V2G during the need to use, there may not be enough charge left to make your desired trip, leading to very complex legal problems if these outcomes resulted in life-altering consequences. Linked to the legal scenarios, the V2G idea could lead to messy and complicated regulations. The stipulation of who owns what property and intellectual property will need to be assigned before the widespread use of V2G (Noel, 2019) as well as a nationally agreed method and communication system, which is unlikely due to companies wanting to make profit from their designs and theories.

2.2.2 Charging Infrastructure

The good side of things for the future is the trend of the average speed of chargers installed around the UK has been increasing at a reasonable rate. Hopefully, this trend carries on at a similar or better rate if the predicted number of EV owners rises by the 88% yearly increase shown by ZapMap.

Number of rapid public charging points by type (2011-to date)



Total rapid connectors: 11418, Updated: 26 November 2021

Figure 6-Increase of charging points shows increase of EV owners

(ZapMap, 2021)

(Welsh Government, 2020) provides a scope that all EV owners by 2025 should feel confident that they will have sufficient charging stations in Wales. However, their paper doesn't consider the exponentially increasing number of EV owners in Wales, and that number will only increase because of the push for lower carbon emissions agreed at COP26 (WRI, 2021) to be in force soon. The paper

does include some interesting points, such as the variety of charging station types suited for different locations, which would make sense as a cost reduction method.

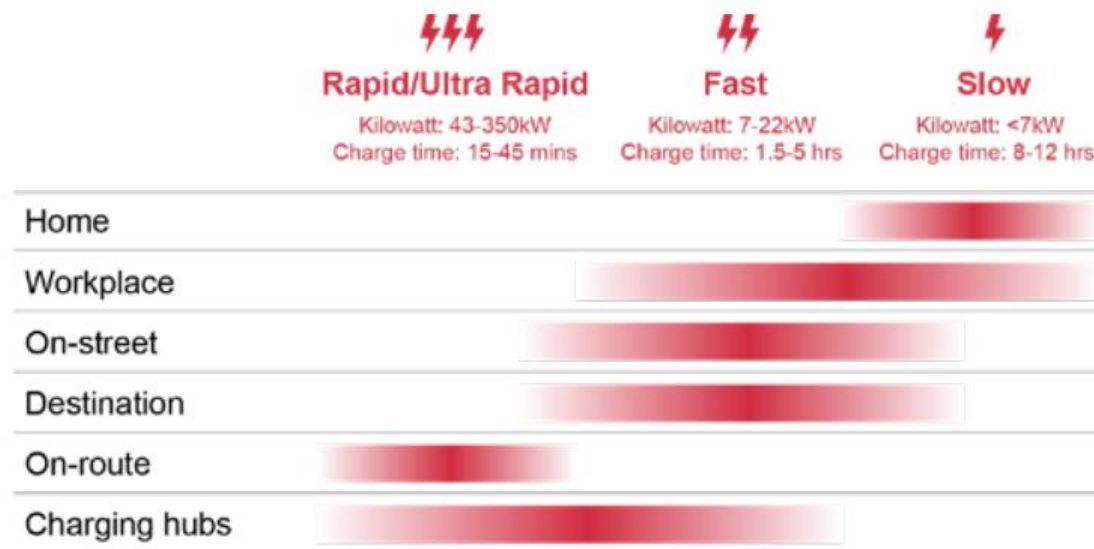


Figure 7-Location vs type of charger

(Welsh Government, 2020)

However, as mentioned earlier, the length of charge is still a massive issue for most people. As referenced by the cost of installing fast chargers in the UK, for the possibility of a wide-spread EV charging network to be feasible, the cost of purchasing(manufacturing) needs to decrease. At this current time, the level of infrastructure can cope with the demands of the quantity of EV's in the UK, but the government need to attempt to follow the nearly 100% increase of yearly EV owners with their own nearly 100% years increase in EV infrastructure, with ideally faster charging capabilities.

Regarding V2G technology, the infrastructure would need to be upgraded to enable Bi-Directional charging, adding another cost element to the adaption to V2G. This may seem like a relatively easy fix, but the main issue is that the likelihood of a universal bi-directional philosophy is very slim. Each company will try and make the most cost-effective solution whilst attempting to convert the market to be theirs. It is mentioned in (Noel, 2019) that the globalisation of communication techniques would need to be created for a harmonious relationship between all V2G points. The governing algorithms will need to be recognised by all charging stations, which ther manufacturers may block to either protect their intellectual property or because they want to be market leaders.

2.2.3 Cost of System

The government cost to implement V2G nationwide would be even more expensive than the widespread employment of EV charging, as the Bi-Directional charging feature would add additional cost and lower the lifetime of the charger due to larger quantities of cyclic discharge (from the Bi-Directional function). As of writing, the current excess of enabling V2G technology to a charger is 3700 GBP. This is likely to decrease in the coming years but that still is a lot of money when considering how many chargers would need to be converted and new ones to have this technology. From earlier writing, the average cost of a fast charger is 3432 GBP, so enabling this V2G function is more expensive than purchasing a relatively slow charger and challenges around costs and processes associated with connecting V2G chargers to various distribution networks. This excess will add up, but (Kaluza, 2021) suggests that the cost of installing a V2G charger could decrease to 1000 GBP in

the future. As well as the stations themselves, the installation and maintenance fees will be larger than petrol stations due to the recentness of the technology, and the limited number of electrical engineers trained in the new technology.

The average cost in the UK for energy is 17.2p per kWh which equated to roughly £5 per 100 miles whereas the average cost for fuel is over double the price of electricity (EDF, 2019). Overall, it is cheaper to own an electric car over time, assuming the cost of energy creation stays relatively similar. If newer methods of energy production were to be used or tested, the average price to charge your EV would increase to fit the increase cost of production. To conclude, the price of owning an EV with V2G would be considerably less, giving the lower cost of charging and the renewal of money by giving energy back to the grid at a set rate, giving the customer a motive to pursue this technology.

3 Discussion

So, is V2G the solution to stabilise the power demands of local communities?

From the literature review of many sources, some significant issues with V2G can be withdrawn and some benefits. V2G does the job it is intended to do. It is proven in the many studies such as (Kaluza, 2021), providing an estimate of 6 Gigawatts of *daily* flexible capacity to the grid if 50% of all EV's in the UK had V2G technology. This number is massive, even more than France's energy supply to the UK from the start of 2021 to September (Bloomberg, 2021). This would help the UK stabilise the national grid fluctuations, as well as EV users to earn some money back from giving energy back to the grid. However, some large negatives need to be evaluated. The main issue is the current battery technology, which cannot support the increase in the number of discharge cycles needed to support a usable V2G system. The constant discharging back into the system would result in much shorter battery lives, giving the EV a shorter lifespan and the battery will need to be discarded much earlier than average. This is highly unethical and unsustainable with current battery make-ups. V2G also poses a difficult business situation, with the potential for the V2G market to be a highly competitive one, with the firms creating new profit battlegrounds for high profit, resulting in cheaper and low-quality chargers and equipment. This undermines the true reason for V2G being an environmentally sustainable system. If done poorly, the expansion of V2G would result in the increase of fossil-fuel and unsustainable energy creation, due to the more considerable energy required to manufacture the chargers and infrastructure, as well as the creation of the energy to put into the grid and EV's in the first place. Having EV's would increase the grid's demand, and V2G does a good job at dispersing that energy; however, it doesn't solve the creation of sustainable energy but only provides another storage zone for the un-sustainably created energy.

To conclude, V2G is a good solution to manage the higher demands of the grid for future electrification, but it would require a massive amount of research and innovation to be a worthwhile short- and long-term implementation. The short-term benefits of V2G are next to 0 as the initial cost of implementing such hardware would massively outweigh the small energy storage provided by the limited quantity of current EVs in the UK. The long-term prospects are better but still flawed due to the significant battery issues and unsustainable first source energy creation. If the government decided to do V2G at any cost, the necessary battery research, public audits/promotion (why would the user care about using V2G? Money-pay back and link with future environmental gains) and company negotiations would need to take place; otherwise, it would be worthless even if money and time was not a concern.

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