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Utility Economics on Vehicle to Grid Charging

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Summary

Vehicle to Grid (V2G) is the logical next step in the transportation electrification revolution, as it allows idle electric vehicles to provide value to the electric grid even when not in use. However, the economics of this technology remain uncertain. This paper examines the financial impact of using a managed charging program versus V2G charging from the utility perspective. The analysis focuses on a hypothetical electric school bus with a 220 kWh battery and a bidirectional 20 kW charger. Results suggest that under certain scenarios, V2G school bus charging can generate a positive net present value for electric utilities based on the value associated with distribution deferrals, avoided capacity purchases, and avoided energy supply purchases.

Keywords: V2G (vehicle to grid), utility, battery, smart charging, electric vehicle

1 Background

1.1 Definitions

V2G technology enables electricity to flow from an electric vehicle's ("EV") battery back onto the electrical grid or directly into a building. The key components of the V2G ecosystem include A) EVs equipped with battery and inverter hardware capable of bidirectional energy flow, B) bidirectional charging equipment that is safely interconnected to the grid, and C) communication software giving grid operators control of charge and discharge. When users are not driving vehicles, their vehicle batteries can act as a form of energy storage capable of accepting or dispatching power, providing a variety of services critical to a safe, reliable, and low-carbon grid of the future. By dispatching energy back to the grid, V2G chargers can realize more benefits than traditional smart charging (e.g., incremental capacity, backup power, load following, ancillary services). At this time, there are few commercially viable, plug-and-play products; however, multiple companies are in development of V2G technology.

Figure 1, below, illustrates how V2G is built upon—and differs from—related charging technologies:

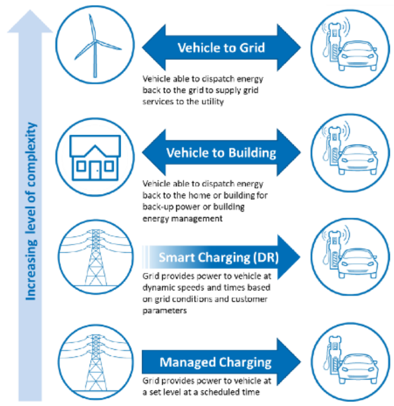

Figure 1: Smart Charging/ V2G Hierarchy

1.2 V2G Charging at Portland General Electric

Portland General Electric (PGE) is a fully integrated investor owned utility located in Portland, Oregon. PGE serves approximately 900,000 customers in Oregon and delivers about 19 million MWh annually. PGE is committed to a clean, reliable, and affordable energy future. Part of this strategy involves the development of a robust transportation electrification strategy, which supports accelerating EV adoption while reducing the cost to serve those vehicles.

Within transportation electrification, PGE has begun to experiment with different electric vehicle charging programs. PGE has a 2013 Nissan Leaf and a bidirectional Princeton Power System CA-10 10 kW DC Quick Charge station located at one of its service centers to test various V2G use-cases. Furthermore, PGE conducted quantitative modelling during the summer of 2019 to explore the potential benefits of V2G charging of electric school buses.

1.3 Industry Review

Although V2G is in a relatively immature state, some research and small-scale tests have already investigated the potential impacts of V2G.

Pacific Gas and Electric (PG&E) has led several research projects related to V2G. In 2017, PG&E tested the efficacy of vehicle-to-home (V2H) charging. Although the team found that EVs can technically provide backup power to a home, V2H is not cost-effective for the customer in an islanding scenario. PG&E also quantified the various value streams of V2G in another study in 2018. Specifically, the study investigated the value of nine V2G benefits: pollution, GHG adder, distribution, transmission, capacity, cap and trade, ancillary services, losses, and energy. All studies from PG&E territory, although helpful, only apply to California territory. The uniqueness of PG&E's territory makes it less applicable to the Pacific Northwest.

There are also several studies specifically analyzing the opportunity to use V2G with electric school buses. The Cajon Valley Union School District submitted a grant application to the Environmental Protection Agency to explore the cost effectiveness of V2G bus charging; however, the available grant application merely provides estimates of the results. As of this writing, it is unclear whether the grant team was successful.

The Massachusetts Department of Energy Resources also studied V2G applications for a fleet of electric school buses. At the time of the study, both electric buses and V2G hardware were extremely nascent.

Mismanagement of charging schedules suggested that V2G was not cost effective without careful management and oversight.

There are also several startups attempting to build the hardware and software necessary to bring V2G to scale. Nuvve, based in California, has led some of the largest deployments around the world testing various V2G value streams. Nuvve has specifically established partnerships with utilities and research institutions enabling V2G pilots in Denmark, France, and the United Kingdom. At the time of this writing, Princeton power systems, an early charging provider, had gone out of business. Wallbox announced its home V2G product at this year's Consumer Electronics Show (CES) but does not anticipate production of a commercially available UL product for some time. Lastly, researchers recently found that Tesla's Model 3 onboard inverters are capable of bidirectional charging, suggesting the future potential of V2G.

Late last year, Dominion Energy announced plans to deploy 1,050 V2G-enabled school buses in partnership with Thomas Built Buses and Proterra. The fleet of buses, when deployed are expected to contain over 100 MWh of energy storage; however, few details have been provided on how the buses will be operationalized.

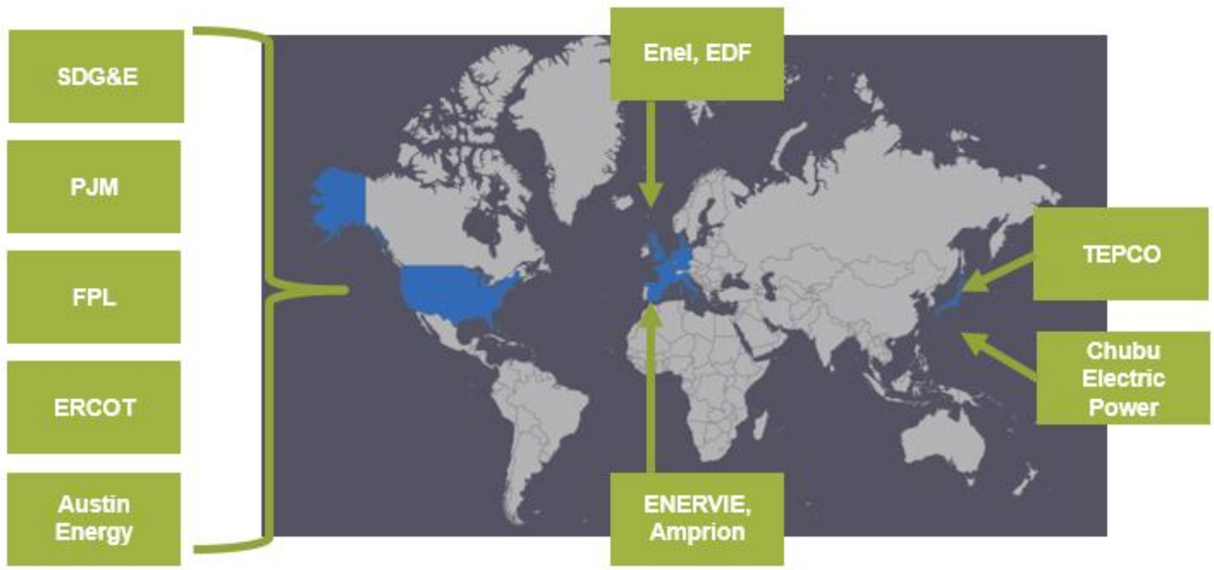

Figure 2: Map of Global V2G Demonstration Projects

2 Methodology

Because few commercially available technologies exist today, this study is based on a hypothetical V2G charging program involving 25 school buses. The study assumed that each bus had a 220 kWh battery and charged using a 19.2 kW L2 AC charger. The analysis assumed that make ready had already been completed and the hypothetical school had already purchased the electric school buses and standard charging infrastructure. The study assumed that the school was responsible for the costs associated with those purchases. The utility was responsible for upgrades to the charging infrastructure to enable bidirectional V2G charging. The purpose of this assumption was to isolate the costs and benefits associated with V2G technology.

2.1 Ratepayer Impact Measure

There are several common tools available to help utilities weigh the costs and benefits associated with new programs. Several of these include Total Resource Cost (TRC), Societal Cost Test (SCT), and Participant Cost Test (PCT) (see Figure 3). These are important tests for future research, as they change the perspective of the test. For example, RIM focuses on the economics from the utility's perspective, whereas PCT will be critical to understanding the benefits to the program participant (EV owner). Modelling this customer perspective will be critical to understanding the customer value proposition of large-scale implementation of V2G.

Test	Acronym	Approach	Focus
Ratepayer Impact Measure	RIM	Compares administration costs and potential bill reductions to a supply-side resource	What are the economic benefits of the program compared to the costs of a supply-side resource?
Total Resource Cost	TRC	Determines whether the total costs of energy in the utility service territory will decrease	Builds on the economic foundation of the RIM test, in some states, this test can include the monetized benefits of avoided emissions or other resource-driven savings
Societal Cost Test	SCT	Determines whether the municipality/state/nation is better off due to the program	Includes economic principles like the RIM and TRC costs. Can also include non-cash costs and benefits such as environmental impact
Participant Cost Test	PCT	Assesses whether the participants benefit from the program	Comparison of the costs and benefits of the customer participating in the program.

Figure 3: Cost Effectiveness Tests

This study used the Ratepayer Impact Measure (RIM) because the study assumed that the school had already borne the upfront cost of the school bus and charging equipment. Nonetheless, the upfront costs of the EV and specialized V2G charging equipment could potentially outweigh the benefits of participating in a V2G program or require such a long-term monetization strategy that the program is impractical. The goal of this study, however, is to understand whether a V2G program will generate greater benefits than costs for the utility's customers (resulting in a net negative impact on customer rates). The RIM test weighs all the costs associated with a program that will impact ratepayers as well as all the benefits that will ultimately flow to the ratepayers. The stream of costs and benefits is extended over the life of the project and discounted to provide a present value. If the total costs are greater than the total benefits, the program could potentially increase utility rates.

2.2 Value Streams

V2G can offer multiple value streams to utilities. The significance of these values depends on the needs of the utility and the customers implementing the V2G program. This study initially considered nine value streams: Energy Supply, Capacity, Distribution Upgrade Deferral, Distribution Capacity, Load Shifting, Emergency Power, Carbon Credit, and Ancillary Services. This study ultimately focused on Energy Supply, Capacity Supply, and Distribution Upgrade Deferral. Though some of these value streams may be mutually exclusive, for the purpose of this exercise, this study assumed values are additive.

Energy Supply: PGE's Integrated Resource Plan (IRP) identifies bulk system needs and provides long-term forecasts. PGE's IRP team has multiple long-term energy supply forecasts, which it uses in its IRP. The IRP forecasts include a high renewables scenario, a carbon tax scenario, and a reference case. This V2G study used the reference case but could easily examine other scenarios in future research. All energy supply units were measured in $/MWh.

Capacity Supply: In most Ratepayer Impact Methodology models, PGE calculates the cost of capacity by running a model to find the "Marginal Capacity MW per Average MW." This number is a ratio which suggests that for every additional MW of capacity added to PGE's load, PGE will need to procure X MW of additional capacity due to the likelihood of an outage given the particular load shape. In an EV context, therefore, this number would apply to any new charging load and be multiplied by the annualized cost of capacity. This study was unable to run multiple scenarios and therefore needed a different way to capture the impact of V2G charging on capacity needs due to varying load shapes.

PGE’s Resource Value of Solar (RVOS) provided an immediate proxy. The RVOS demonstrates that the capacity impact differs depending on the hour. The RVOS demonstrates that distributed generation provides a capacity benefit to the utility. Instead of procuring additional—often costly—capacity through bilateral trades, the utility can access that capacity through distributed generation. Because renewables do not offer the same reliability of base load generation, however, that value must be discounted. PGE’s RVOS demonstrates the capacity value that distributed solar offers depending on the time of day and year. RVOS provides capacity value estimates in a $/MWh based on a 12 x 24-hour schedule. This 12 x 24 format is critical to demonstrate that electricity injected onto the grid during peak times offers a greater capacity benefit than electricity provided during off-peak times. In fact, additional electricity during off-peak times, such as 1:00 AM, provides $0 value according to RVOS. The V2G study assumed that every additional MWh of electricity injected onto the grid through V2G charging has the same value as electricity injected onto the grid by solar. This is a significant assumption, and further modelling is necessary to better understand the locational and temporal values of electricity derived from car batteries.

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	16.8	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	19.6
8	51.3	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	42.0
9	65.4	15.8	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	1.8	60.8
10	48.3	10.3	0.0	0.0	0.0	0.0	0.0	0.5	0.1	0.0	1.1	45.9
11	37.7	6.4	0.0	0.0	0.0	0.0	0.1	1.3	0.2	0.0	0.7	37.4
12	25.6	4.3	0.0	0.0	0.0	0.0	0.4	3.5	0.4	0.0	0.5	32.3
13	19.7	2.8	0.0	0.0	0.0	0.0	1.9	9.7	1.1	0.0	0.4	24.2
14	16.9	1.7	0.0	0.0	0.0	0.2	4.8	20.0	2.5	0.0	0.3	18.9
15	15.8	2.1	0.0	0.0	0.0	0.3	10.3	46.4	4.9	0.0	0.3	15.2
16	16.8	2.3	0.0	0.0	0.0	0.4	13.0	24.9	11.1	0.0	0.7	21.6
17	48.3	5.9	0.0	0.0	0.0	0.5	16.3	28.9	6.3	0.0	2.6	70.6
18	53.6	11.2	0.0	0.0	0.0	0.5	15.0	36.6	10.0	0.0	2.9	47.8
19	81.0	21.0	0.0	0.0	0.0	0.5	19.8	46.7	14.7	0.1	5.5	73.9
20	78.9	26.6	0.0	0.0	0.0	0.8	21.8	38.8	10.7	0.0	5.5	64.1
21	57.1	19.4	0.0	0.0	0.0	0.7	16.0	65.3	7.9	0.0	3.7	45.5
22	34.3	12.8	0.0	0.0	0.0	0.2	5.8	31.4	7.4	0.0	2.1	26.9
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 4: Generation Capacity values ($/MWh) based on the 2019 IRP

Distribution Upgrade Deferral: Smart management of distributed generation assets enables PGE to better manage its transmission and distribution grid. This paper strictly examined the grid benefits associated with deferred upgrades to the distribution grid—not transmission infrastructure. The value behind deferred upgrades comes from the time value of money that comes with delaying infrastructure upgrades and associated expenses to the future. PGE would still need to make the distribution upgrades eventually, but smart management of EV structure could enable PGE to save ratepayer dollars in the present and space out those upgrades over time.

The V2G model used distribution capacity deferral values presented in the RVOS filing. Again, RVOS quantified the impact of distributed solar on the distribution grid by month and hour in $/MWh. Therefore, the study once again assumed that the impacts of distributed solar can serve as a proxy for V2G charging. Nonetheless, future studies should re-examine the impacts of V2G charging on the distribution grid at a more granular level as these values assume system averages. Specific areas of the local distribution system may have substantially more or less value depending on their specific constraints (or lack thereof).

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	76.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.0
10	76.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.9
11	76.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.9
12	75.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.1
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	77.2	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	77.5	79.2	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	79.2	81.0	0.0	0.0	0.0	78.1
18	80.6	0.0	0.0	0.0	0.0	0.0	80.4	81.9	0.0	0.0	0.0	82.1
19	81.1	0.0	0.0	0.0	0.0	0.0	79.7	80.9	0.0	0.0	0.0	81.4
20	79.4	0.0	0.0	0.0	0.0	0.0	77.6	78.3	0.0	0.0	0.0	79.7
21	76.9	0.0	0.0	0.0	0.0	0.0	0.0	76.6	0.0	0.0	0.0	77.4
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 5: Distribution Capacity Deferral values ($/MWh)

2.2.1 More on PGE

This study used the reference case electricity prices that informed Portland General Electric's 2019 Integrated Resource Plan and generation capacity values and distribution upgrade deferral values from other publicly available dockets.

The values assigned to capacity and distribution upgrade deferrals were provided in $/MW and suggested that every MWh injected onto the distribution grid had a different monetary worth depending on when the energy entered the grid. The distribution deferral values represent an indicative system-wide average: any V2G deployment would require a location-specific analysis to determine the distribution upgrade deferral values

Table 1: Data Sources

Measure	**Source**	**Value or Unit**
Energy Supply Forecast	Confidential	$/MWh
Energy Capacity	PGE RVOS	$/MWh
Distribution Deferral	PGE RVOS	$/MWh
Customer Pricing	Schedule 38	$/MWh

3 Results

This study demonstrated that a V2G electric school bus program can create marginal value for utility ratepayers by reducing the cost of utility operations. Figure 6 depicts how the utility avoids electricity supply and generation capacity purchases on the open market and may be able to defer costly distribution upgrades. Specifically, the value added (represented in orange) is the combined *negative cost* associated with the avoided electricity supply, generation capacity, and distribution upgrades. One can see that the V2G scenario generated the greatest negative cost, thereby creating the greatest value for utility ratepayers.

Furthermore, one can see that in the modelled V2G scenario, the utility received additional revenue (represented in blue) due to the additional charging necessary to replenish batteries after the V2G discharge. However, additional revenues were offset by a payment to the customer (represented in green) to ensure that the customer is not paying for additional electricity solely for the purpose of participating in V2G services.

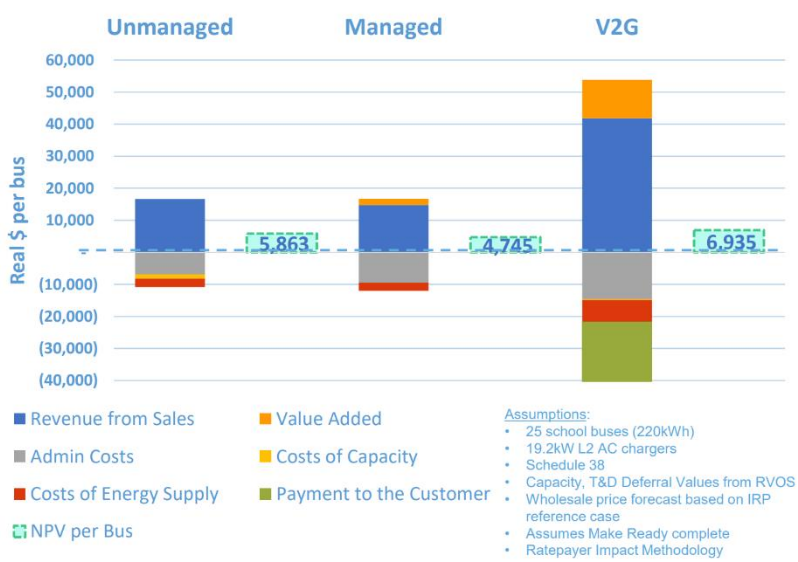

Figure 6: Incremental Costs and Benefits of Charging Programs

3.1 Unmanaged

In the unmanaged charging scenario, an electric school bus merely plugged in and began charging as soon as the driving shifts were completed. An unmanaged scenario generated a positive NPV in the RIM primarily because of the increased revenue from electricity sales. Each charging scenario assumed the bus owner used Schedule 38. Schedule 38 is a time of use (TOU) rate for large energy consumers. Therefore, if the bus charged after completing its afternoon route, it would have to pay PGE a higher retail rate during those hours. The unmanaged scenario provided a baseline and assumed no V2G infrastructure was in place. Figure 7 represents a charging schedule of a typical school bus.

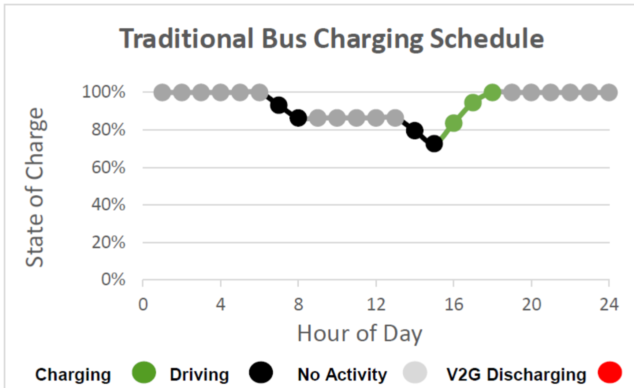

Figure 7: Bus Charging Schedule in an Unmanaged Scenario

3.2 Managed

In a managed charging scenario, the utility had control over the timing of the electric school bus charging and again assumed the bus owner was on TOU Schedule 38. However, there were no energy discharges (i.e., no use of bidirectional V2G capabilities) in this scenario. This also generated a positive NPV in the RIM; however, managed charging generated less revenue from sales for the utility because charging now took place during the off-peak hours. According to the model, the money PGE receives when users consume energy during peak times outweigh the savings of energy supply and capacity at those times (which could yield different rate schedules). Even though there were fewer costs associated with Generation Capacity purchases, the decreased electricity sales revenues lowered the NPV overall.

Although the managed charging scenario results in a lower NPV in the RIM test, managed charging does improve the Participant Cost Test. This is an important consideration for fleet operators considering EVs.

3.3 V2G

In the V2G scenario, school buses charged *and discharged* according to a schedule managed by PGE. In this scenario, the school bus charged during off-peak hours, except for a one-hour charge between the morning and afternoon driving shifts, so it could discharge electricity throughout the afternoon peak. Figure 8 represents a modelled simulation of a potential V2G load profile.

In the V2G scenario, PGE received monetary benefit from the three value streams described in section 2.2.

First, PGE was able to procure electricity from the school buses instead of procuring those resources on the open market.

Second, PGE could rely on the capacity provided by the school buses instead of procuring capacity during peak hours through operating generation assets or conducting bilateral trades.

Third, PGE could defer costly distribution upgrades if the deployments of V2G charging infrastructure were strategically located to address constraints on the distribution system. Values for actual deferred upgrades would be higher or lower depending on site-specific considerations.

The V2G scenario also assumed that PGE would have to compensate customers for their participation in the V2G program. This is represented by the green segment of the value stack labelled as "payment to the customer." This study assumed that PGE would pay the customer the retail value of the electricity generated during the V2G discharging times. This study assumed that PGE would not pay the participating customer value for the avoided capacity cost and distribution deferral value.

The value of avoided energy supply, avoided capacity, and distribution deferral generated new value for the utility and resulted in the best NPV of the three scenarios.

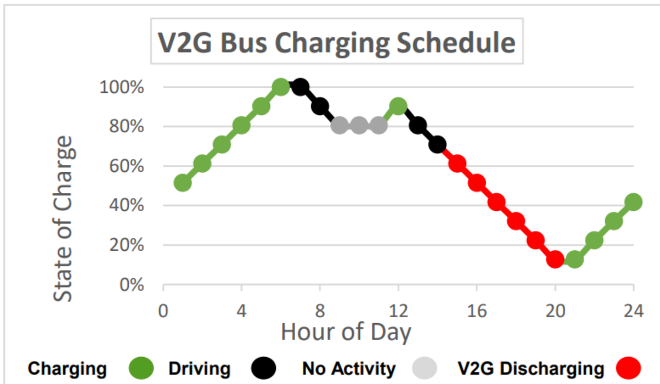

Figure 8: Bus Charging Schedule in a V2G Scenario

4 Conclusions and Areas for Further Research

4.1 V2G Can Add Marginal Benefit to Utility Charging Programs

The primary finding of the study is that the V2G charging technology used for electric school buses can add value to electric utilities according to the RIM test. Specifically, V2G drives value through avoided energy supply costs, avoided generation capacity costs, and distribution upgrade deferrals. Ultimately technology (vehicle connectivity, charging speeds, etc.), utility system needs, and customer dwell time will dictate the precise value for a specific project.

4.2 Utilities Should Start Planning, Testing, Valuing V2G Resources Today

Significant steps are required for utilities to effectively maximize the value that can be realized by V2G in the future. Utilities could:

1. Conduct long-term system planning on bulk system, distribution system, and EV adoption to identify the value streams and where potential V2G deployments make economic sense for the grid and the customer.
2. Leverage economic modelling tools to estimate the value of V2G.
3. Establish a Distributed Energy Resource Management system with integrations of charging service providers and vehicle manufacturers.
4. Test and demonstrate emerging V2G technologies to pilot and operationalize controls, validate the value streams in the field, evaluate customer experience impacts, and inform future program design.

4.3 Partnerships Are Needed Between Utilities, Vehicle OEMs, and Charging OEMs

Buy-in from Original Equipment Manufacturers (OEMs) is critical to the future of V2G. The electric vehicle ecosystem not only involves the utility, but also manufacturers of the charging infrastructure and producers of the vehicles themselves. Vehicle OEMs need to ensure that the onboard inverters are capable of bidirectional charging. Charging OEMs must have clear communication protocols, so V2G programs can share data between the vehicle and the utility. Utilities have the opportunity to create ratepayer value, but all must proactively work together to that end.

4.4 Topics Warranting Further Research

Value Streams: This study investigated three value streams: avoided energy supply, avoided capacity, and distribution upgrade deferrals. There are other potential value streams associated with V2G programs that warrant further research. Future studies may include Participant Cost Tests, Total Resource Cost Tests, and Societal Cost Tests. Utilities may also consider implications of carbon pricing in future analyses. V2G technology—both on the charger side and the vehicle side—remains limited and costly. Additional modelling with storage optimization simulations should be run to identify optimal value streams from V2G utilization.

Customer Acceptance: Further analysis should be conducted to gain additional insights into customer willingness to adopt V2G technologies. Because this study assumed that the participant already purchased the electric bus and installed basic charging infrastructure, it does not provide insight into the customer's willingness to pay for V2G technology. Given the recent announcements by Dominion, Proterra, and Wallbox related to V2G investment, additional customer interviews and scenario analysis is warranted to fully understand the potential value of V2G.

Battery Degradation: The impact of V2G charging on battery degradation and warranty design requires further research. Although several researchers have examined battery degradation in a laboratory setting, further research is necessary to understand the impact of irregular, everyday V2G charging.

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