Appendix E. Figures and Tables Supporting PGE Responses to Stakeholder Comments

This section contains figures and tables supporting PGE Responses to Stakeholder Comments found in Appendix D. Those comments and responses are excerpted below to provide context for those reading through this section.

> ***Stakeholder Comment:*** *Present the average observed load shape of residential charging in 2022 from the Company's vehicle-based data and residential EVSE data.*
>
> ***PGE Response:*** *PGE appreciates Staff's discussion about the importance of EVSE data from PGE's pilot programs. At the time of filing the draft TE Plan, our Residential Smart EV Charging pilot evaluation was just getting underway and therefore we did not include any findings from this ongoing effort, including consolidated load shape data. PGE plans to leverage pilot evaluation findings in future model updates and will share the evaluation memo with Staff and stakeholders following the associated pilot evaluation timeline.*
>
> *Notwithstanding that, certain draft data have been made available since filing the draft TE Plan. Figure 24, below, shows the average observed load shape from our residential Smart Charging pilot evaluation for both EVSE (Group A) and vehicle-based data (Group B).*

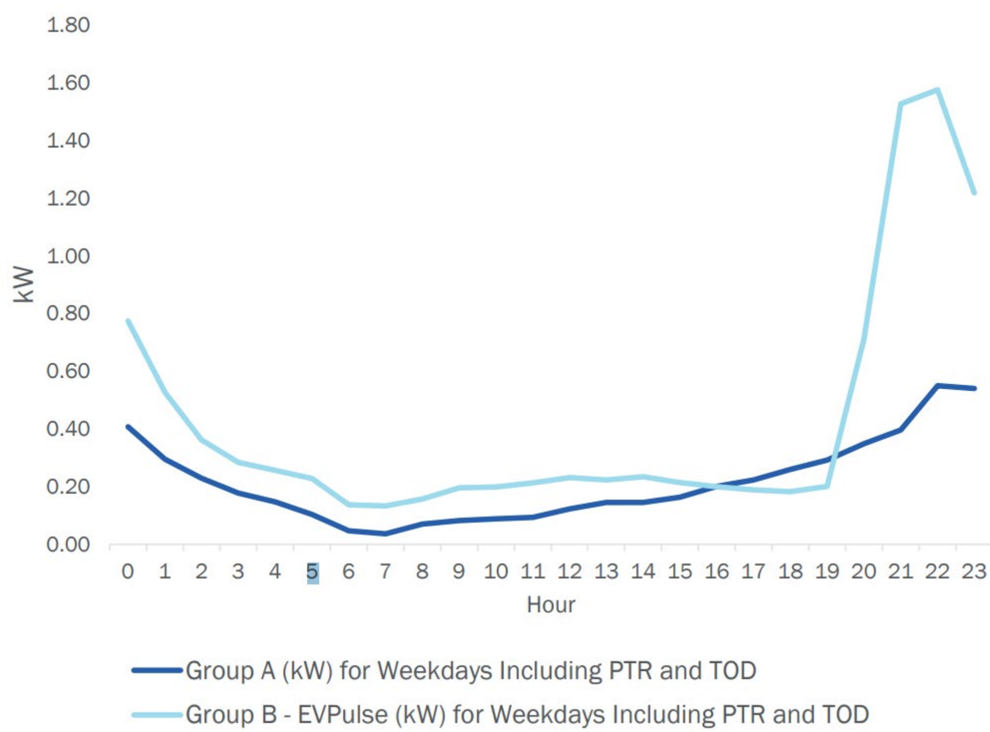

Figure 24. Average Weekday Load Profile - Summer 2022 - Draft Results from Residential Smart EV Charging Pilot Evaluation Analysis

Stakeholder Comment: *Identify which hours were selected as peak hours in response to OPUC IR 32*

PGE Response: *The methodology to derive MW peak impacts from AdopDER described in response to OPUC IR 32 identifies 2-4 hour time windows (including hour of day, day of week, month of year) where the loss of load probability is high. Our MW summaries indicate the EV load impact during these events. Table 86, below, shows the peak hours identified using this method for 2026.*

Table 86. Peak Hours Identified in Response to IR 032

Month	Peak Hours
January	2026-01-02 07:00:00-08:00
January	2026-01-02 16:00:00-08:00
January	2026-01-07 16:00:00-08:00
January	2026-01-08 16:00:00-08:00
January	2026-01-09 16:00:00-08:00
January	2026-01-21 07:00:00-08:00
January	2026-01-21 16:00:00-08:00
January	2026-01-22 16:00:00-08:00
January	2026-01-23 07:00:00-08:00
January	2026-01-23 16:00:00-08:00
July	2026-07-21 17:00:00-07:00
August	2026-08-05 17:00:00-07:00
August	2026-08-10 17:00:00-07:00
August	2026-08-12 17:00:00-07:00
August	2026-08-26 17:00:00-07:00
December	2026-12-31 16:00:00-08:00

Stakeholder Comment: Put forth a modeling change to better reflect the economics of heavy-duty vehicle fleet operators

PGE Response: PGE clarifies that we do not solely rely on the ACT rule-based market percentage requirements for new MDHDV vehicle sales, given that AdopDER is a hybrid model. We also include a bottom-up analysis to identify likely fleet conversions, developed with information from our Customer teams, Key Account managers, and TE outreach leads.

These bottom-up estimates are used to inform the short-term forecast (since ACT requirements do not kick in until 2024). We also supplement the long-term forecast of electric HDV based on market panel survey data because the current ACT rule that Oregon has adopted reaches max market share of 40 percent for Class 7-8 tractors in 2035. We have compared our previous methodology for estimating MDHDV market share described in Appendix G of PGE's DSP Part I filing[328] with the currently approved Oregon ACT rules. The results demonstrate close alignment of the forecasts and underscore the uncertainty facing this market. Figure 25 below shows a comparison of these two methods to highlight the fact that the ACT rule market share requirements falls well within the established boundaries identified by our market research efforts.[329]

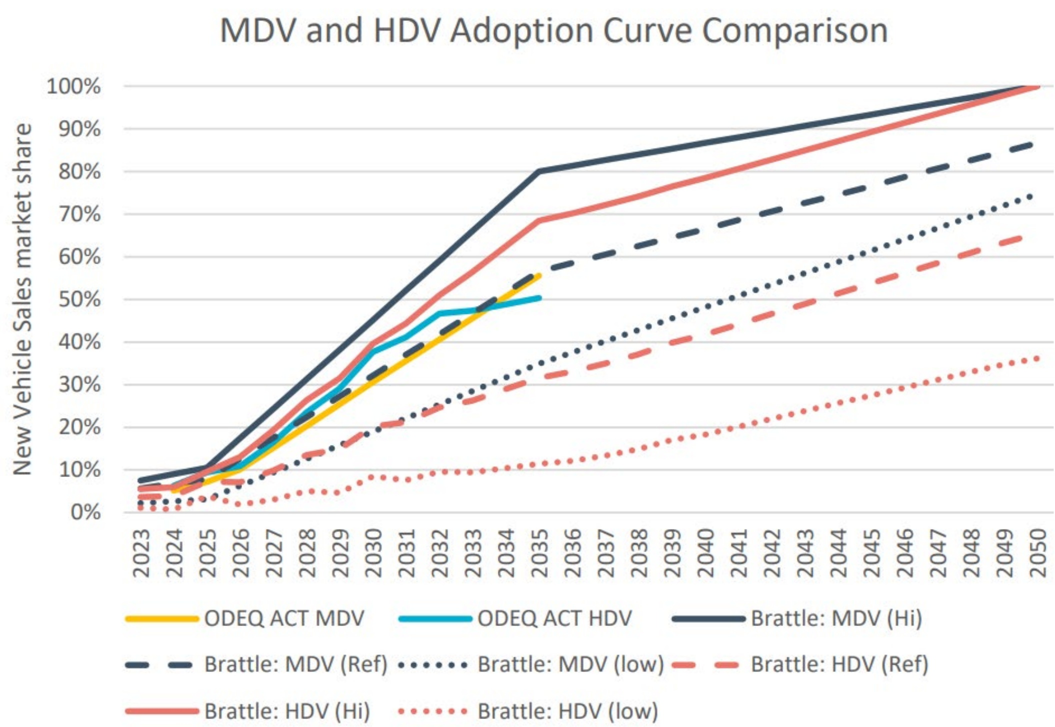

Figure 25. Comparison of Annual EV Sales Percentages for MDHDV from Oregon's ACT Rule and PGE's Market Research

328 Keeling, Schaefer, Goldman, Light, Hledik, Sergici (Cadeo). *DER and Flexible Load Potential – Phase 1, Appendix A* describes the previous MDHDV methodology, retrieved from https://assets.ctfassets.net/416ywc1laqmd/1sMpwIkeZ0Imb9FuEA7F2i/128e4ffc0bc044f2fde8dcd7cbdc03c6/2021-09-17-pge-der-flex-load-potential-phase1.pdf.

329 Note the MDV and HDV market shares from ODEQ ACT shown below have been weighted across the different vehicle sub-types for purposes of comparison.

PGE continues to monitor this market closely and participates in a number of external industry activities aimed at better clarifying the pace and scope of MDHDV electrification trends. For example, PGE is one of 16 founding electric company members of the recently launched EVs2Scale2030 project, led by the Electric Power Research Institute.[330] *We will update our methods surrounding HDV economics and forecasting accordingly as new information matures and better data becomes available.*

With regard to Staff's interpretation of the recent CARB agreement, wherein Staff states a concern that Oregon "may devolve into a hub for secondary used Diesel trucks," PGE sees the agreement language between CARB and the different Parties to the new Clean Truck Partnership as underscoring the commitment on the part of engine and vehicle manufacturers to meeting the standards.

Importantly, the agreement specifically states the joint commitment to meet not just the Advanced Clean Trucks rule as it existed on March 15, 2021 (the version which corresponds to Oregon's current adopted rules) but also California's recent 100 percent ZEV sales requirement adopted April 28, 2023.[331]

Therefore, PGE disagrees that any new special analysis is required to anticipate a potential shortfall of the HDV forecast in our AdopDER model, because our low forecast scenario already anticipates a potential lower compliance rate than ACT specifies, and there is likewise significant upside to the forecast high case given that California has implemented the percent ZEV sales requirement for MDHDV on April 28, 2023.

PGE anticipates that with more adoption experience in the HDV market segment, the forecast accuracy will improve similar to the observed convergence Staff identifies have occurred with respect to the LDV forecast share.

[330] See https://www.epri.com/about/media-resources/press-release/7D9bQbqC8e9MldOQ8R5ChO.
[331] See Appendix B pg. ii of the recent Agreement, available at: https://ww2.arb.ca.gov/sites/default/files/2023-07/Final%20Agreement%20between%20CARB%20and%20EMA%202023_06_27.pdf.

Appendix F. Division 87 Concordance

Table 87, below, provides a reference as to how this filing addresses Division 87 rules applicable to the portfolio of activities. Appendix C.1 Public Charging - Municipal Charging Collaboration and Appendix C.2 Business and Multi-family Make-ready Solutions address how new activities proposed within this filing meet the rules applicable thereto.

Table 87. Division 87 Concordance (Rules 1-3, for the Transportation Electrification portfolio)

Division 87 Rule	Section(s) that Address the Rule
(1) This rule prescribes the required elements of an electric company's Transportation Electrification Plan (TE Plan). The objective of the TE Plan is to:	
(a) Integrate the electric company's transportation electrification actions into one document. The Plan shall include, but is not limited to, the electric company's portfolio of near-term and long-term transportation electrification actions, including applications for program(s), and infrastructure measure(s), planning and expenditure of the Monthly Meter Charge, and other transportation electrification actions such as PGE Clean Fuels programs.	Chapter 7, Appendix A, Appendix C
(b) Act as a summary of the electric company's investments and activities, which may include investments and infrastructure for electric vehicles of various sizes, rate design, programs, and services, reasonably expected to achieve the objectives of Oregon Laws 2021, chapter 95. The TE Plan shall seek to address areas most affected by market barriers in the electric company's service territory, prioritize load management, and to provide benefits for underserved communities.	Chapter 9
(2) An electric company must file for Commission acceptance of a TE Plan.	The full filing will meet this requirement
(a) As used in this rule, "acceptance" means the Commission finds that the TE Plan meets the criteria and requirements of this rule and does not constitute a determination on the prudence of the individual actions discussed in the TE Plan. The Commission may accept the TE Plan subject to conditions. Acceptance, or acceptance subject to conditions, shall constitute approval of the electric company's program applications and TE Budget as filed in the TE Plan and its appendices. Non-acceptance means that the TE Plan does not meet the criteria or requirements of this rule.	
(b) An electric company must present a draft TE Plan to Commission staff and stakeholders for review and comment on or before May 1, every three years starting in the year 2025, or as otherwise directed by the Commission. The TE Plan shall include the three calendar years after the year the TE Plan is presented.	This filing is consistent with this requirement and direction given utilities in

Division 87 Rule	Section(s) that Address the Rule
	Commission Order No. 21-484[332].
(c) The electric companies will work with Commission staff to propose a schedule to parties for draft TE Plan review, comment, and workshops.	PGE will work with Commission staff and stakeholders to propose an appropriate review process and schedule.
(d) After public review of the draft TE Plan, the electric company must file a final TE Plan with the Commission, noting how the electric company responded to parties' comments.	PGE will comply, continuing the stakeholder engagement laid out in Chapter 5, as well as additional responses as laid. out in Appendix D.
(e) Commission staff will present its recommendation on the electric company's TE plan at a public meeting. The Commission shall also consider party and electric company comments and recommendations on a TE Plan at the public meeting before issuing an order of acceptance. The Commission may provide direction to an electric company regarding any additional analyses or actions that the electric company should undertake in its next TE Plan.	n/a
(f) An electric company may propose TE Plan updates at any time between scheduled TE Plan filings. An electric company is required to file a TE Plan update for material changes to its TE Plan. Material changes are new TE program or infrastructure measure applications, or program or infrastructure measure changes that require new incremental ratepayer dollars. Commission staff will work with parties to propose a schedule for public review of TE Plan updates.	PGE will comply in the event an update to the TE Plan or Budget is necessary during the 2023-2025 cycle.
(3) The TE Plan must include	
(a) The current condition of the transportation electrification market in the electric company's Oregon service territory, including, but not limited to:	Chapter 4
(A) A discussion of new state policies and programs since the last TE Plan filing;	Section 4.1.1
(B) Market barriers that the electric company can address and other barriers that are beyond the electric company's control, including any identified	Section 4.6

[332] OPUC Order No. 21-484, retrieved from https://apps.puc.state.or.us/orders/2021ords/21-484.pdf.

Division 87 Rule	Section(s) that Address the Rule
emerging challenges to transportation electrification, charging, and vehicle technology updates;	
(C) Existing data reasonably accessible to the electric company on the availability, reliability, and usage patterns of charging stations;	Section 4.7
(D) Number of electric vehicles of various sizes in the utility service territory and projected number of vehicles in the next ten years;	Section 4.3.1
(E) Other transportation electrification infrastructure, if applicable; and	Section 4.5
(F) A forecast of public and private charging infrastructure needed in the company's service territory to support transportation electrification. The forecast should utilize a Commission-approved tool to estimate needed public charging infrastructure over the next ten years and include type, location and timing of needed infrastructure.	Section 4.4
(b) A summary of the electric company's transportation electrification portfolio of program(s) and future transportation electrification concepts and actions in its Oregon service territory for the next three years. The summary should include the company's long-term vision for its TE portfolio and strategy to support transportation electrification in its service territory. The TE Plan must incorporate project lessons learned and any other relevant information gathered from other transportation electrification infrastructure investments, programs, and actions to ensure that lessons learned are carried forward to the next TE Plan;	Chapter 7
(c) A discussion of how programs and infrastructure measures in the TE Plan holistically advance performance area categories that include, but are not limited to:	Chapter 8
(A) Environmental benefits including greenhouse gas emissions impacts;	Section 8.1
(B) Electric vehicle adoption;	Section 8.2
(C) Underserved community inclusion and engagement;	Chapter 5, Section 8.3
(D) Equity of program offerings to meet underserved communities;	Section 8.4
(E) Distribution system impacts and grid integration benefits;	Section 8.5
(F) Program participation and adoption;	Section 8.6
(G) Infrastructure performance including charging adequacy which considers, but is not limited to reliability, affordability, and accessibility;	Section 8.7

Division 87 Rule	Section(s) that Address the Rule
(d) Supporting data and analysis used to develop the TE Plan, which may be derived from elements such as review of costs and benefits, rate design, energy use and consumption, overlap with other electric company programs, and customer and electric vehicle user engagement;	Chapter 9
(e) A discussion of the electric company's potential impact on the competitive electric vehicle supply equipment market, including consideration of alternative infrastructure ownership and business models, and identification of a sustainable role for the electric company in the transportation electrification market;	Section 7.4
(f) Analysis of the estimated ratepayer impact of the TE Plan over the next three calendar years; and	Section 9.7
(g) The electric company's TE Budget. The TE Budget must include: (A) Annual budgets for the TE Plan for the three calendar years after the year the TE Plan is presented to Commission Staff and stakeholders. The annual budgets should include a discussion of the context of anticipated long-term expenditures for the next ten years, including but not limited to benefit-cost analysis "cost tests;"	Chapter 9
(A) A forecast of all expenditures to support transportation electrification grouped by program and/or infrastructure measure, and further divided into:	Section 9.2
(i) Capital expenditures; and	Section 9.2
(ii) Expenses, separating administrative costs, O&M on investments, incentives paid to program participants, and any other unique category as relevant;	Section 9.2
(B) A forecast of all funding sources to be utilized, including but not limited to, the Monthly Meter Charge, grants, Oregon Clean Fuels Program credits, base rates, and deferrals based on a reasonable estimate, including a discussion of how actual revenue might vary from the estimate;	Section 9.3
(C) A forecast of all spending on underserved communities, grouped by program and/or infrastructure measure and further divided into:	Section 9.4
(i) Expenditures of funds collected through the Monthly Meter Charge as required by Oregon Laws 2021, chapter 95 Section 2;	Section 9.3.1
(ii) Spending from revenues other than the Monthly Meter Charge, including but not limited to grants, Oregon Clean Fuels Program credits, base rates, and deferrals;	Section 9.3
(D) The Commission's acceptance of the electric company's TE Plan will constitute approval of the TE Budget, which includes the Monthly Meter Charge budget as required by Oregon Laws 2021, chapter 95 Section 2.	n/a

Appendix G. PGE Whitepaper on V2G

Utility Experience with Vehicle-to-Grid Regulatory and Technology Challenges, and the Final Hurdles to Large-Scale V2G Deployment

Ian Beil[1], Luke Whittemore[1], and Anik Shrestha[2]
[1]*Grid Edge Engineering,* [2]*Transportation Electrification*
Portland General Electric, Portland, Oregon
{ian.beil, luke.whittemore, anik.shrestha}@pgn.com

***Abstract*—Advancements in electric vehicle charging equipment, vehicle battery improvements, and technical standards updates have led to a recent proliferation of vehicle-to-grid (V2G) demonstration projects that presages a dramatic increase in V2G deployments worldwide. This paper discusses one utility's initial experiences in developing a regulatory framework for customer participation in V2G. It also covers the technical barriers encountered when implementing several V2G demonstration projects, and considers the final barriers that remain before V2G chargers are widely installed across the power system.**

***Index Terms*—Electric Vehicles, Vehicle-to-Grid, Distributed Energy Resources**

I. Introduction

Motivated by carbon reduction goals and improved product performance, consumers and businesses are adopting electric vehicles (EVs) at a rapid pace. The exponential growth of EVs and their accompanying electrical infrastructure requirements has compelled system planners to think deeply about how these resources will be integrated into the power grid in a way that is convenient to the user, avoids malignant impacts to the electric provider, and is cost effective for all parties involved. One avenue that has the potential to reduce costs for consumers and provide flexibility to the utility is vehicle-to-grid (V2G) technology, in which the EV's on-board energy storage can be utilized to send power back to the grid through the EV's associated Electric Vehicle Supply Equipment (EVSE).

While V2G technology has existed since the early 2000's [1], it has taken many years for EVSE vendors to commercialize products that offer bi-directional charging. There are a number of reasons for this - initial technology limitations, firming up standards to include V2G capability, and a lack of obvious revenue streams - that will be discussed throughout the paper. Nonetheless, breakthroughs in these areas have led to recent V2G demonstration projects, and the time is ripe for much wider deployments of V2G-capable EVSE in a number of applications.

This paper briefly discusses some of the early efforts involving V2G charging and more recent commercial deployments. It then pivots to discuss some of the last hurdles that must be overcome before wide-scale V2G adoption, including regulatory and policy considerations as well as technological challenges. Finally, it covers the experiences that Portland General Electric (PGE) has had installing two separate V2G chargers - one a passenger vehicle charger located at a PGE facility, and the second a larger V2G-capable electric bus charger located at a customer's school bus depot.

Portions of this work were funded through the Oregon Clean Fuels Program

II. Past V2G Efforts

The possibility of using EVs to provide V2G services has existed since Kempton and Tomić [1] first proposed and patented the technology in the early 2000's. Since then, considerable research has gone into understanding how V2G resources could be integrated into the grid, including discussions of the possible transmission impacts of large fleets of V2G vehicles [2], considerations of the required communication and control infrastructure [3], as well as analysis of both the technical and social barriers preventing early adoptions [4]. A recently published textbook [5] provides a comprehensive overview of many of these issues.

The economics of V2G have also gained considerable attention. Previous research analyzing how V2G revenue could affect vehicle purchase economics [6, 7] indicates that the technology can pencil out provided that the correct compensatory structures are put in place. Using V2G to provide ancillary services [8], participate in energy markets [9], and offer reactive power support [10] has also been considered, and these options are likely to become more viable in the United States as FERC Order 2222 is fully integrated across ISO/RTO environments.

Managed charging of electric vehicle fleets employing V2G has also been studied extensively, both to provide energy to the grid at times of peak system demand [2, 4, 11] and to relieve more local distribution system bottlenecks [12, 13]. These analyses indicate that V2G could provide substantial benefits over uni-directional charging by offering increased system flexibility. Indeed, a review of past EV research [3] indicates that the total amount of energy stored in V2G-capable EVs could match or even exceed the amount of stationary battery energy storage deployed on many power systems in the near future. If managed in a coordinated fashion, the potential for V2G as a dispatchable resources is quite large.

Given these insights into the potential benefits of bi-directional EV charging, a number of V2G demonstrations have been conducted over the years. In the US, this includes early efforts to integrate a V2G-capable vehicle into the California ISO [14] and at an Air Force base [15]. There are also several incidents where V2G chargers were incorporated into microgrid environments [16, 17]. While all notable efforts, these tended to contain one-off prototype technology that was not yet fit for large-scale commercialization. Of particular interest to this paper are the more recent deployments of V2G technology, all within the last two years, and all utilizing commercial off-the-shelf EVSE chargers. These include an electric school bus and charger deployed at Pekin, Illinois [18], a five bus V2G testing site deployed in White Plains, New York [19], and a larger-scale project involving both passenger vehicles and electric buses employing V2G technology within Southern California Edison service territory [20]. Together, these projects seem to represent the start of a much larger push for V2G adoption within the US.

PGE has also recently deployed a pair of V2G projects within its service territory, which are discussed in Section V. First though, Sections III and IV discuss some of the barriers that were encountered during project execution. The lessons learned during these endeavors may be of use to other industry participants as they navigate their own V2G deployments.

III. Regulatory and Policy Barriers to V2G Adoption

The potential for V2G - or "batteries on wheels" - presents a challenge for regulatory and policy analysts. Should these resources be treated the same as stationary energy storage assets? Can they deliver the same level of reliability? And what are the implications of a utility or third-party aggregator directly controlling both charging and discharging of a customer's vehicle?

A. Tariffs and Rate Design

As of publication, there were few, if any, widescale V2G electricity tariffs available within the US. Several pilot tariffs have been or are in development for the projects mentioned above, but these tend to be available to only a select few participants. As previously mentioned, without the ability to compensate vehicle owners that provide power back to the grid, it is difficult to justify the added project costs of V2G-equipped EVSEs.

General considerations for designing a V2G electric rate structure include:

- **Lack of Precedents** - While V2G tariffs do exist in EU and UK markets, there is a paucity of existing examples in the United States. This puts increased pressure and visibility on any initial V2G tariffs from a US electricity provider.
- **Comparison to Stationary Storage** - There are tariffs available for instances where US utilities directly control and dispatch stationary battery energy storage assets. Of course, since a V2G battery can drive off at any moment, it begs the question of how these resources should be compensated compared to an asset that is generally available 24/7.
- **General Rate Design** Special consideration must be given to the implications that a rate structure will have on V2G operations at scale. Particular approaches could include net-metering, time-of-use rates, or more dynamic pricing structures. Poor rate design could have the unintended effect of causing vehicles to dispatch at off-peak times rather than aligning V2G discharge to the grid at peak times when the energy is most valuable.
- **Demand Charges** An EVSE that can charge and discharge at a high rate may be more valuable to the power system than a lower-powered model; however, demand charges could inadvertently punish an EV customer that is providing this higher degree of flexibility by charging a flat rate for the peak energy used during a billing cycle. For instance, a customer providing ± 50 kW of bi-directional charging is more useful than a customer providing ± 25 kW, but the former customer could potentially see much higher demand charges, therefore disincentivizing them from providing the full range of their EVSE power capability to the grid. Care must be taken to avoid this type of misaligned incentive.
- **Equity Considerations** Policy makers and electricity providers have a duty to design rates in a way that promotes equity among ratepayers. For instance, the Oregon Public Utility Commission (PUC) has stated [21] that distribution system planning must "identifying grid needs, implemented in partnership with communities and community-based organizations" that "create value-adding investments for communities, and align the energy system with community priorities." Discussions around V2G rate structures must consider how they will impact low-income customers and those for whom EV adoption may be more difficult to attain. Early research in this space [22] indicates that additional studies and consideration are warranted to better understand the social dimension of V2G charging.
- **Control of Customer Assets** Any form of managed charging, whether uni-directional or V2G, must contemplate the implications of a utility or third-party aggregator gaining control over a customers asset, especially one as critical to daily life as an automobile.

All of these consideration make designing V2G tariffs a challenging process. It is anticipated that the ongoing discourse between electricity providers and PUCs across the country on this subject will lead to more widely-available V2G rates in the very near horizon.

B. Interconnection Agreements

Typically in the US, any resource that backfeeds onto the distribution system is required to file an Interconnection Request and eventually sign an Interconnection Agreement that specifies how the asset can operate. These agreements legally bind the customer's resource to provide features such as anti-islanding control during outages, and may specify compliance with standards such as IEEE 1547-2018.

The Interconnection Agreement process tends to be highly regimented and specific to each state. The necessary adjustments to this process to include V2G-capable resources are not considered particularly onerous. Nonetheless, it does require coordination between electricity providers, state regulators, and relevant stakeholders to make the changes necessary to allow V2G resources to file such Interconnection Requests.

C. Market Participation of V2G Resources

Besides direct payment from the utility to a customer providing V2G services, there is also the possibility of an EVSE or aggregation of EVSEs to engage in an energy or ancillary services market in order to receive compensation. In the US, this process is currently being overhauled to comply with FERC Order 2222, which will impact the value proposition of V2G resources in ISO/RTO environments. In more vertically-integrated environments such as the West's Energy Imbalance Market outside of California, it remains to be seen how V2G-capable chargers and related distributed energy resources will be engaged with market operations.

IV. Technological Barriers to V2G Adoption

The past twenty years have seen considerable advancements in both EV charging equipment and battery technology that has made V2G a more viable economic proposition.

A. Battery Degradation

The earliest and most daunting issue facing V2G operation was the prospect of increased battery degradation over time. All chemical batteries experience a waning of their power and energy capacity as they experience charge/discharge cycles. For the lithium-ion batteries installed in most EVs, the implication used to be that battery life did not extend past the 7-10 year range (under uni-directional charging and normal driving patterns). V2G charging inherently increases the number of charge/discharge cycles that a battery endures, and thus may shorten its life and decrease the value proposition of V2G participation. Indeed, early research indicated that V2G charging would require multiple battery replacements over the life of an EV [23].

More recent studies, however, suggests that these concerns may be overstated (for a review, see [24]). While V2G operation does have a measurable impact on battery life, at least one empirical study [25] has demonstrated that the effect on battery capacity is not much more impactful than standard uni-directional charging. There is evidence [26] that keeping the battery within a 30-90% state-of-charge, for instance while providing frequency regulation services, tends to minimize degradation under V2G charge/discharge cycles.

Adding to these observations is the increasing prevalence of V2G-capable vehicles on the commercial market. Anecdotely, several electric bus manufacturers now offer V2G capability standard. This is indicative of reduced concerns over V2G-induced battery degradation that manufacturers now have.

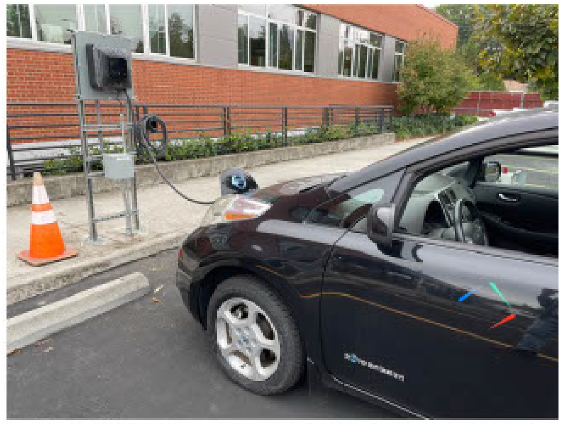

Fig. 1. A Nissan LEAF undergoing V2G testing at PGE's Portland Service Center with a Quasar Wallbox charger. The 240 V, 32 A bi-directional charger can provide up to 7.2 kW of power from the vehicle battery to the grid. Successful testing of the charger's V2G capability was conducted in October 2021, with ongoing efforts underway to study the efficiency and reliability of the charge/discharge process.

B. Ongoing ISO 15118 Standard Update

One issue that, as of publication, is still being resolved is the ongoing revision process of the ISO-15118 standard. This standard specifies how vehicles and EVSEs communicate under V2G conditions. While several V2G charger manufacturers have been able to find near-term workarounds for this issue, once the revisions are officially in place, they will prevent the need for these type of "bootstrapped" solutions and make it easier for EVSE vendors to manufacture V2G-capable equipment.

C. Integration with Utility Control Infrastructure

Another ongoing integration challenge revolves around how electricity providers and third parties interact with distributed energy resources on the grid. This will require coordination with both utility-owned advanced distribution management systems and third-party operated distributed energy resource management systems.

The IEEE 2030.5 standard is anticipated to aid in the communication between EVs and other entities. Increased deployment of IEEE 2030.5-compatible equipment, both by the customer and the electricity provider, should aid this transition and enable managed charging of both uni-directional and V2G resources.

V. Experience with V2G Demonstrations at PGE

PGE installed and operated two separate examples of V2G technology in the 2021 timeframe - one a passenger vehicle charger, the other an electric school bus charger. Both are discussed below.

A. Utility-owned passenger vehicle charger

In an effort to gain access to early V2G technology, PGE purchased a European model residential charger, the Quasar

Fig. 2. The (very shiny) display of the V2G-equipped passenger vehicle charger. The negative sign convention on the -6.1 kW reading indicates that the vehicle is engaged in V2G discharging to the grid. The display also shows the vehicle's current state-of-charge (71%).

Wallbox, in 2021. The charger was installed at a PGE-owned facility, obviating the need for an Interconnection Agreement and related complexities. Installing the charger came with a few key challenges:

1) The charger uses the ChadeMO connection, and thus a Nissan LEAF is the only compatible US vehicle that can be used to test it. PGE had several LEAFs in its fleet and was able to assign one for testing. It also required a trip to the dealership to have the vehicle configured to allow for V2G operation (this functionality is typically disabled for customers).
2) As a European model, the charger expected a 240 V connection via one hot and one neutral wire. Since the US distribution system configuration requires two hots to provide 240 V service, a specialized ground fault current interrupting circuit breaker was required for the installation. Testing by the electrical contractor ensured that the breaker correctly operated during faulted system conditions.
3) In order to avoid additional service upgrades to the distribution equipment at the site, the charger had to be installed at a location where there was significant background load to prevent net backfeed to the grid. PGE's Portland Service Center was chosen as the hosting site, given its higher ambient loading and its general accessibility for fleet vehicles.

The Wallbox model was successfully installed in October 2021, and initial testing demonstrated the ability of the EVSE to discharge power back to the grid as well as charge the vehicle. The listed bi-direction power capacity of the model is ±7.68 kW (at 240V, 32 A), and these levels were achieved in both directions. During initial trials, the battery of the vehicle has been successfully discharged from 90% state-of-charge down to 65% and back to 90%.

Additional testing is underway at the site. The research plan for the charger includes assessment of its round-trip efficiency during a discharge/charge cycle and its ability to perform several charge/discharge events back-to-back. Efforts are also underway to tie the resource to existing PGE control systems and allow for remote dispatch. If achieved, this would allow the parked vehicle to discharge power back to the grid during peak loading conditions, thus integrating it into a nascent virtual power plant.

B. Electric School Bus V2G Charger

The PGE Electric School Bus initiative, with funding provided through Oregon Clean Fuels Program, give school districts access to capital that can be used to purchase electric school buses and associated charging infrastructure. One local customer, the Newberg School District, in conjunction with their transportation provider First Student, applied for and received funding for a V2G-capable vehicle and charger to be installed in 2021. This project featured a 155 kWh Blue Bird bus and a 60 kW bi-directional Nuvve charger.

As a customer-owned endeavor, this project presented additional challenges during implementation compared to the PGE-owned charger. For instance, this was the first V2G resource to go through PGE's Interconnection Agreement process, and required some adjustments to the pro forma language included in the attendant documents.

It was also necessary to determine the required electrical infrastructure for the V2G charger. Eventually, the PGE Electrical Service Requirements for PV generation were utilized by the distribution engineers studying the project. These include stipulations that a utility-accessible manual disconnect switch be located adjacent to the customer-owned switchgear. The EVSE was also required to comply with the IEEE 1547-2018 standard and have gained full UL-certification.

The charger will also be integrated into PGE control systems via an IEEE 2030.5-compatible server. Similar to the passenger vehicle charger, this integration will allow the electric school bus to be dispatched as part of a larger virtual power plant operation.

There is ongoing dialogue in the state of Oregon with a number of stakeholders around potential V2G tariffs, and PGE looks forward to being able to offer compensation to customers who provide this valuable service.

VI. Conclusion

While vehicle-to-grid (V2G) technology was original developed decades ago, it seems poised to finally reach a level of large-scale commercial success in the near future. As discussed throughout this paper, the barriers to mass adoption include regulatory and legal hurdles such as updates to interconnection processes, questions about appropriate electricity rate structures, and considerations for how a customer's vehicles can and should be controlled. There are also a few technical bottlenecks related to standards updates and integration with utility and third-party control systems that need to be resolved.

Still, the big picture outlook is bright. Two recent demonstration projects by PGE are discussed in this paper, which together may foster larger-scale tests and help to visibly promote the technology. Ongoing cooperation by electricity providers, equipment manufactures, and a range of customers will be required to make broad V2G deployments a reality.

References

[1] Willett Kempton et al. "Vehicle-to-grid power: battery, hybrid, and fuel cell vehicles as resources for distributed electric power in California". In: *Prepared for the California Air Resources Board and the California Environmental Protection Agency* (2001).

[2] Willett Kempton and Jasna Tomić. "Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy". In: *Journal of power sources* 144.1 (2005), pp. 280–294.

[3] Francis Mwasilu et al. "Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration". In: *Renewable and sustainable energy reviews* 34 (2014), pp. 501–516.

[4] Benjamin K Sovacool and Richard F Hirsh. "Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition". In: *Energy Policy* 37.3 (2009), pp. 1095–1103.

[5] Lance Noel et al. *Vehicle-to-Grid*. Springer, 2019.

[6] Michael K Hidrue and George R Parsons. "Is there a near-term market for vehicle-to-grid electric vehicles?" In: *Applied Energy* 151 (2015), pp. 67–76.

[7] Joachim Geske and Diana Schumann. "Willing to participate in vehicle-to-grid (V2G)? Why not!" In: *Energy Policy* 120 (2018), pp. 392–401.

[8] Eric Sortomme and Mohamed A El-Sharkawi. "Optimal scheduling of vehicle-to-grid energy and ancillary services". In: *IEEE Transactions on Smart Grid* 3.1 (2011), pp. 351–359.

[9] Ali T Al-Awami and Eric Sortomme. "Coordinating vehicle-to-grid services with energy trading". In: *IEEE Transactions on smart grid* 3.1 (2011), pp. 453–462.

[10] Mithat Can Kisacikoglu. "Vehicle-to-grid (V2G) reactive power operation analysis of the EV/PHEV bidirectional battery charger". In: (2013).

[11] Taraneh Ghanbarzadeh, Sassan Goleijani, and Mohsen Parsa Moghaddam. "Reliability constrained unit commitment with electric vehicle to grid using hybrid particle swarm optimization and ant colony optimization". In: *2011 IEEE Power and Energy Society General Meeting*. IEEE. 2011, pp. 1–7.

[12] Nuh Erdogan, Fatih Erden, and Mithat Kisacikoglu. "A fast and efficient coordinated vehicle-to-grid discharging control scheme for peak shaving in power distribution system". In: *Journal of Modern Power Systems and Clean Energy* 6.3 (2018), pp. 555–566.

[13] Ahmed Yousuf Saber and Ganesh Kumar Venayagamoorthy. "Optimization of vehicle-to-grid scheduling in constrained parking lots". In: *2009 IEEE Power & Energy Society General Meeting*. IEEE. 2009, pp. 1–8.

[14] Alec N Brooks et al. *Vehicle-to-grid demonstration project: Grid regulation ancillary service with a battery electric vehicle*. California Environmental Protection Agency, Air Resources Board, Research ..., 2002.

[15] Chris Marnay et al. *Los angeles air force base vehicle to grid pilot project*. Tech. rep. Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States), 2013.

[16] Mart Van Der Kam and Wilfried van Sark. "Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study". In: *Applied energy* 152 (2015), pp. 20–30.

[17] M Abul Masrur et al. "Military-based vehicle-to-grid and vehicle-to-vehicle microgrid—System architecture and implementation". In: *IEEE Transactions on Transportation Electrification* 4.1 (2017), pp. 157–171.

[18] M. Kramer. *Pekin adds first electric school bus in US that will communicate with the power grid*. Pekin Daily Times. May 2021. URL: https://www.pekintimes.com/story/news/education/2021/03/23/pekin-has-first-vehicle-grid-bus-united-states/6973152002/.

[19] Green Car Congress. *Con Edison testing V2G service from 5 electric school buses*. Dec. 2020. URL: https://www.greencarcongress.com/2020/12/20201211-coned.html.

[20] P. Griffo. *Can Your Electric Car Be Used to Help Power the Grid?* Edison International. May 2020. URL: https://energized.edison.com/stories/can-your-electric-car-be-used-to-help-power-the-grid.

[21] Portland General Electric. *Distribution System Planning: The Foundation of clean, reliable, and affordable energy*. 2021. URL: https://portlandgeneral.com/about/who-we-are/resource-planning/distribution-system-planning.

[22] Benjamin K Sovacool et al. "The neglected social dimensions to a vehicle-to-grid (V2G) transition: a critical and systematic review". In: *Environmental Research Letters* 13.1 (2018), p. 013001.

[23] Justin DK Bishop et al. "Evaluating the impact of V2G services on the degradation of batteries in PHEV and EV". In: *Applied energy* 111 (2013), pp. 206–218.

[24] Jingli Guo et al. "Impact Analysis of V2G Services on EV Battery Degradation-A Review". In: *2019 IEEE Milan PowerTech*. IEEE. 2019, pp. 1–6.

[25] Andreas Thingvad et al. "Empirical Capacity Measurements of Electric Vehicles Subject to Battery Degradation from V2G Services". In: *IEEE Transactions on Vehicular Technology* 70.8 (2021), pp. 7547–7557.

[26] Alain Tchagang and Yeong Yoo. "V2B/V2G on Energy Cost and Battery Degradation under Different Driving Scenarios, Peak Shaving, and Frequency Regulations". In: *World Electric Vehicle Journal* 11.1 (2020), p. 14.

Appendix H. Brattle Economic Variables

Table 88. Brattle Economic Variables

Variable Name	Variable Type	Description
Dependent Variable: EV sales per capita	Continuous	Defined as the total incremental sales of EV (BEV or PHEV) per million residents
State incentives	Continuous	The maximum incentive (rebate, tax credit or tax exemption) offered by a state upon purchase of a BEV or PHEV, in $/vehicle
Clean Vehicle Credit	Continuous	A federal tax credit (FTC) offered by the federal government upon purchase of a BEV or PHEV, in $/vehicle
Total Incentive	Continuous	Sum of the state incentives and FTC
Battery price	Continuous	Lithium-ion battery cost index in $/kWh, as a proxy of electric vehicle cost (BNEF)
Vehicle miles travelled (VMT)	Continuous	Average vehicles miles travelled annually, per capita
EV-ICE fuel cost ratio	Continuous	Ratio of operating costs of an EV ($/100 miles) to that of an ICEV ($/100 miles)
Tesla Cap dummy	Binary	A dummy variable to indicate a period of spike in EV sales after Tesla hit the cap for the FTC Q3'18 and Jan'19
Model availability	Continuous	Number of EV models available across a state by year
Green views score	Continuous (0-100)	Average environmental voting score of state House and Senate reps (League of Conservation Voters Annual Environmental Scorecard)
High Occupancy Vehicle (HOV) lane exemption	Binary	Indicates the presence of an HOV lane exemption for EVs
Traffic density	Continuous	Weighted average daily traffic per lane for all principal arterials
Zero Emission Vehicle (ZEV) mandate	Binary	Indicates the presence of a ZEV mandate enacted by the government
EV charging rate	Binary	Indicates whether or not at least one utility offers an EV rate for charging in a given state

Appendix I. Commission Dockets Which Approved Funding of TE Activities

Table 89. Commission Dockets Which Approved Funding of TE Activities

	Funding Source	Approval Action	Year(s) Approved	Detail
Business & Multi-Family Make-Ready Solutions	Customer Ratepayer	UM 2033; Order No. 23-147	2023	Capital spend referenced in 2023 MMC budget
	MMC	UM 2033; Order No. 23-147	2023	2023 MMC Budget expansion of ratepayer program
Fleet Partner Pilot	Customer Ratepayer	Approval letter 6/1/21; Adv. No. 21-09	2021	Program application approved with tariff
	MMC	UM 2033: Order No. 23-147	2023	2023 MMC Budget expansion of ratepayer program
Heavy Duty Charging Pilot	Customer Ratepayer	Order No. 21-195; Adv. No. 21-03	2021	Approved 6/15/2021
Public Charging – Electric Avenue and Municipal Charging Collaboration	Customer Ratepayer	UM 2033: Order Nos. 22-381 and 23-147	2022 and 2023	Capital spend referenced in 2022 and 2023 MMC budgets
	MMC	UM 2033: Order Nos. 22-381 and 23-147	2022 and 2023	2022 and 2023 MMC Budgets
	Deferral	UM 1938; Order No. 21-475	2021	Electric Avenue
Business EV Charging Rebates	MMC	UM 2033; Order No. 22-381	2022	2022 MMC Budget expansion of deferral program
	Deferral	UM 2003; Order No. 22-263; Adv. Nos. 20-19 and 21-15	2020 and 2021	Deferral program (expanded with 2022 MMC)
EV Ready Affordable Housing Grants	MMC	UM 2033; Order No. 22-381	2022	2022 MMC Budget only
Residential Smart Charging Pilot	MMC	UM 2033: Order No. 22-381	2022	2022 MMC Budget expansion of deferral program

	Funding Source	Approval Action	Year(s) Approved	Detail
	Deferral	UM 2003; Order No. 22-263; Adv. No. 20-18	2020	Deferral program (expanded with 2022 MMC)
Portfolio Support	Customer Ratepayer	N/A		Utility CapEx
	MMC	UM 2033: Order Nos. 22-381 and 23-147	2022 and 2023	2022 and 2023 MMC Budgets

Appendix J. Substantive Changes between the Draft and Final Filing

This section provides a recap of substantive changes based on stakeholder comments to the draft TE Plan. Details regarding

Table 90. Substantive Changes between the Draft and Final Filing

Description of Change	Location in Document
Shift in program spend from the Business and Multi-family Solutions expansion to Public Charging - Municipal Charging Collaboration and Electric Avenue to address stakeholder concern regarding price parity at multi-family locations. The re-purposed funding remains consistent in support of multi-family charging with the same number of ports (approximately 100 ports). Due to this shift, municipal charging curbside make-ready ports increased by an additional ~100 make-ready ports which will be co-located at or near other programs' multi-family sites.	Appendices C.1 and C.2
Change in rebate incentive for the multi-family portion of Business and Multi-family Solutions to address stakeholder concern regarding the prices property owners could charge tenants. The program provides the same charger rebate amount as other business programs up front ($1,000) with an option to earn an additional $1,300 at the end of five years (to support potential charger replacements) if prices charged have remained within 10% of Schedule 50 prices.	Appendix C.2.1.5
Monthly Meter Charge funding increased from draft plan due to using unallocated dollars for changed programs (Public Charging - Municipal Charging Collaboration).	Table 3 shows increased MMC budget amount from draft plan filing.
Increased portfolio costs due to inclusion of general rate base program manager O&M costs in Public Charging - Municipal Charging Collaboration, and the increased amount of spend needed to support 100 curbside charging ports instead of 100 multi-family parking lot make-ready ports.	Table 2 and Table 3
Schedule 50 principles are included in how PGE is considering redesign this tariff.	Section 7.2.2.2