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A New Direction:
Considerations for Vehicle-to-Grid Rate Design

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Executive Summary

Electrified transportation presents new challenges for electricity grid managers in the form of new load on an already constrained distribution grid. Price signals in electricity tariffs are important tools grid managers use to encourage alignment of electricity consumption with carbon emission reductions, reduced system costs, and other policy goals. The introduction of Vehicle-to-grid (V2G) technology, which delivers energy back to the grid, poses a new frontier for the practice of employing retail electricity rates to encourage specific customer behaviors. V2G is suited to provide certain grid and societal services but will require avenues for compensation for these services. Revenues from compensation for V2G services can enhance equity in the electrified transportation sector. Utilities, electric vehicle aggregators, and policymakers can look to existing retail rates and programs, but must also weigh the unique nature of vehicles as grid assets, when shaping compensation mechanisms to target specific grid services and policy outcomes for optimal deployment and utilization of V2G technology.

Keywords: electricity, policy, utility, electric vehicle (EV), V2G (vehicle to grid)

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1. Introduction

Customer-side electric vehicle (EV) resources introduce new load on an already constrained distribution grid and also may deliver energy back to the grid through vehicle-to-grid (V2G) technology. Through the structure of tariffs, utilities and system operators send price signals to consumers to encourage or discourage various types of consumption. Many utilities have begun to offer rates aimed at mitigating issues that unmanaged, unidirectional EV charging can impose on the distribution system [1], [2]. V2G technology is an emerging solution that poses a new frontier for the practice of employing retail electricity rates to encourage specific customer behaviors.

1.1 Context and Existing EV Rates

In the absence of widespread retail access to real-time volumetric pricing, common utility approaches have included introducing EV-specific rates, EV rates that incorporate time-of-use structures, and EV rates that address barriers posed by demand charges.

1.1.1 EV-specific Rates

EV-specific rates take advantage of the relative flexibility of EV load without exposing other less flexible end uses to these more varied prices. These can include rates that provide differential pricing for EV charging, those that include costs for utility-owned charging infrastructure, or those that pair clean energy with EV electricity consumption. A research effort from Lawrence Berkeley National Laboratory (LBNL) and E9 Insights, which included development of a comprehensive database of EV tariff offerings, identified 217 EV-specific retail rates from investor-owned utilities across 38 states and the District of Columbia [1].

1.1.2 EV TOU Rates

EV rates that incorporate time-of-use (TOU) structures reflect the differentiated cost to supply energy across seasons and hours. TOU rates set fixed prices that are differentiated across predetermined time blocks – for example, specifying peak, off-peak, and super off-peak pricing periods over the course of the 24-hour day. An impetus for establishing EV-specific rates is to take advantage of EV load flexibility without exposing less flexible end uses to price variations. According to the forthcoming LBNL report, period-based temporal differentiation is "the single most common rate design element in currently offered EV-specific rates" [1]. Other similar approaches include bill credits or penalties for response to peak demand or "critical" events. Summary statistics from the LBNL report illustrated in Figure 1 present the number of EV-specific rates categorized by approach to temporal differentiation, such as hourly, periodic (multi-hour periods over a 24-hour day), or seasonal.

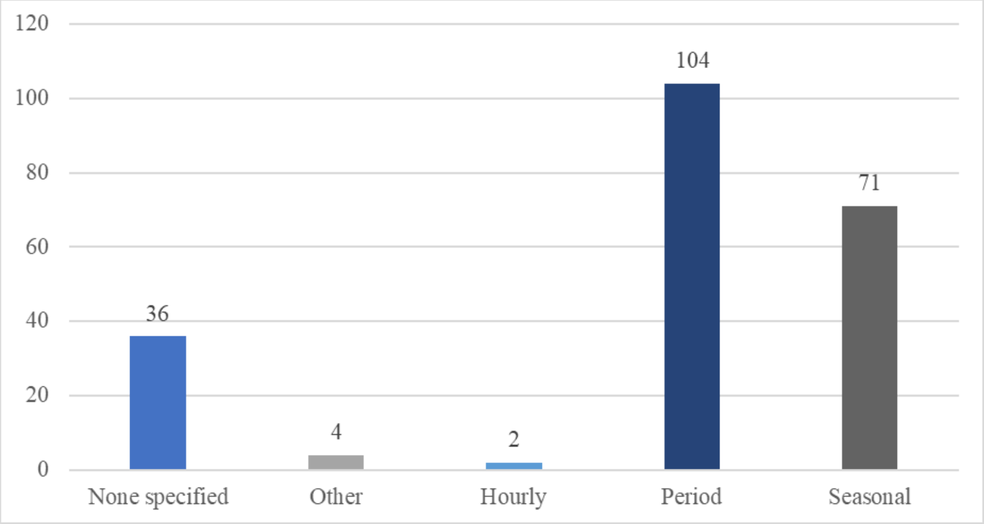


Figure 1: Count of EV-Specific Rates By Temporal Differentiation [1]

1.1.3 EV-specific Demand Charge Solutions

EV rates for commercial and industrial customers that address barriers posed by demand charges, which have been deemed to "promote inefficient deployment and dispatch of energy storage and EV charging" and to "undercut" the economics of transportation electrification [3]. A 2021 analysis by E3 found that EV TOU rates that include high non-coincident demand charges (charges based on customer peak usage independent of system-wide peaks) could push load into peak periods. This could increase overall system costs relative to unmanaged charging on a flat rate [4].

Despite these critiques, utilities require a mechanism for recuperating fixed capacity-driven costs of the electric grid. In the absence of holistic approaches that more exactly assign capacity-related costs to a customer based on location and time of their system utilization, utilities have turned to other near-term solutions to demand charge issues.

The main avenues utilities have employed are subscription demand charges and demand charge credits or holidays. Utility rates with subscription demand charges present tranches of peak demand capacity to customers and require them to select their allocations in advance. Customers that manage to stay within their selected tranche receive discounted prices, but peak demand consumption beyond the subscribed capacity amount incurs penalty costs. Prominent examples of this approach are Pacific Gas and Electric's (PG&E) Business EV (BEV) rate plans and San Diego Gas & Electric's (SDG&E) EV-HP Pricing Plan [5, 6].

The more widespread approach utilities have pursued is to provide temporary demand charge relief through credits, discounts, and holidays, all of which are meant to be phased out as the EV industry matures. Examples include Southern California Edison's (SCE) TOU-EV Rates and Pepco's EV Charging Distribution Demand Charge Credit Rider [7, 8].

Innovative proposals to improve demand charge design include the introduction of a dynamic capacity charge based on actual grid utilization or a demand charge based on marginal costs or marginal emissions [9]. In their 2021 paper, E3 proposes an alternative rate structure that utilities can offer to aggregators of EV load that includes both a dynamic energy charge based on the day-ahead energy price and, for residential EV load, a dynamic demand charge [4]. Notably, this dynamic demand charge would be designed to minimize distribution system load coincident with local peaks at the substation, circuit, service level, or even final line transformer or secondary distribution line. Such approaches have been implemented on limited bases, principally for commercial and industrial customers, such as:

1. SCE's Retail Automated Transactive Energy System (RATES) pilot [10]
2. Valley Clean Energy and PG&E Agricultural Pumping Dynamic Rate Pilot [11, 12]
3. Georgia Power Real Time Pricing – Day Ahead Schedule [13]

Further investigation of real-time pricing and EV rate design to incentivize vehicle operators to charge in ways that are less costly and burdensome to the electricity grid is warranted. Innovative approaches to demand and energy components of EV rates can combined, as is being done under a 2021 decision by the California Public Utilities Commission (CPUC) directing PG&E to offer Optional Day-Ahead Real Time Rates as an alternative to the TOU generation component of the BEV rate that also contains a subscription demand fee [14].

The next section explores the emerging solution of vehicle-to-grid (V2G) transfers and discusses how retail rates can be employed to encourage flexible bidirectional vehicle load to serve as a grid resource through injections back to the grid.

2. V2G Rates on the Horizon

Flexible bidirectional vehicle load can serve as a grid resource to mitigate the impacts of EV charging on the distribution system and affirmatively support the grid through provision of grid services. Revenues from compensation for V2G services can also enhance equity in the electrified transportation sector by improving the economics of electrification and serving in place of costly and polluting peaker plants.

2.1 Context and Existing V2G Rates

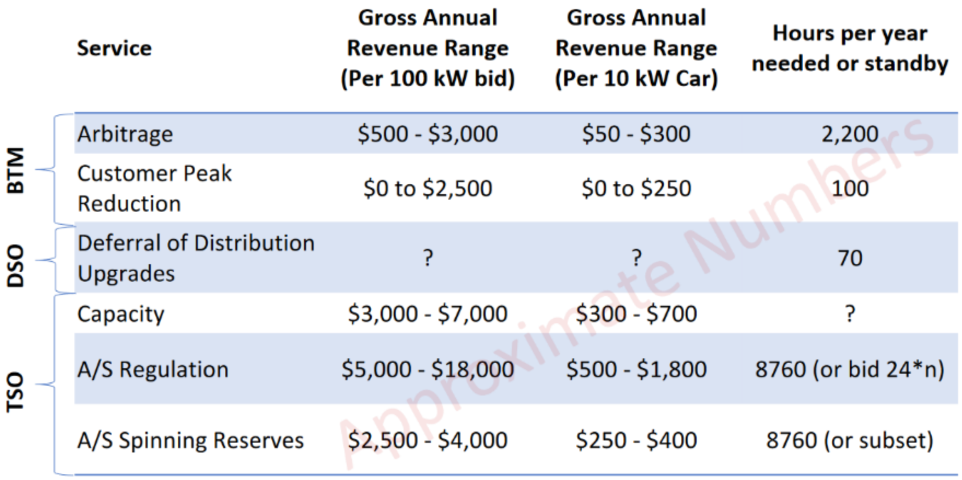
Vehicle-to-grid (V2G) is the process by which a mobile energy source, such as the battery in an electric vehicle, has bi-directional capabilities that allow the battery to send energy back to the main grid when connected to a charging site. V2G has potential to support the grid if implemented with the right price signals. A V2G rate should compensate for energy or other services provided back to the grid, less any transaction costs. Because this technology is relatively new, and untested at scale, there is not widespread agreement on the value of grid services and system benefits that V2G creates and how it should be compensated.

In principle, a rate that compensates for V2G need not be specific to vehicle technologies; for example, a mechanism intended to compensate for stationary storage may cover the appropriate value streams. Nonetheless, solutions to compensate for vehicle energy export should reflect that, unlike most other distributed energy resources (DERs) that export to the grid, a vehicle's role as an asset in the electricity market is secondary to its primary purpose of providing transportation. The element of mobility also means that power injections can occur in different locations on the grid. This may mean that distinct processes and standards are necessary to integrate vehicle energy onto the grid or that V2G should be treated as functionally having a lower "capacity factor" than other DERs. Another practical rationale for V2G-specific rates may be in cases where there are not explicit markets for specific grid services. In the absence of robust market mechanisms, V2G rates that appropriately compensate for services provided may be necessary to encourage economically efficient adoption of the technology.

2.1.1 Potential Grid Services from V2G

Because V2G technology is relatively new, and untested at scale, there is not widespread agreement on the value of grid services and system benefits that V2G creates and should be compensated for. Several noteworthy analyses provide initial indications:

1. In 2017, NREL identified three primary V2G services: bulk energy storage, operating reserves, and frequency regulation [15].
2. In 2020, the California Joint Agencies Vehicle-Grid Integration Working Group ("the Working Group") considered 80 V2G use cases [16]. Of these, 48 were identified to present value to the broader system, rather than just to customers, through services of: backup/resiliency, Day-Ahead Energy, frequency regulation, GHG reduction, grid upgrade deferral, resource adequacy/flexible capacity, local capacity, system capacity, renewable integration, and voltage support. However, only one of these, V2G in the Commercial – Workplace sector to enable grid upgrade deferrals, was assessed to have a favorable balance of cost, benefit, and near-term implementation feasibility. The Working Group's medium-term policy recommendations indicated that, with policy clarity, V2G resources could also offer Day-Ahead Energy and Resource Adequacy System services.
3. In a 2020 presentation to PJM's Emerging Technologies Forum, researchers from the University of Delaware and Exelon laid out estimated valuations for the stack of services that EVs can offer to various market actors (Figure 2) [17]. They suggest that customers can realize behind-the-meter value from arbitrage and customer peak reduction, that distribution system operators can get value through deferrals of system upgrades, and that transmission system operators will be able to compensate for ancillary services like regulation and spinning reserves.



	Service	Gross Annual Revenue Range (Per 100 kW bid)	Gross Annual Revenue Range (Per 10 kW Car)	Hours per year needed or standby
BTM	Arbitrage	\$500 - \$3,000	\$50 - \$300	2,200
	Customer Peak Reduction	\$0 to \$2,500	\$0 to \$250	100
DSO	Deferral of Distribution Upgrades	?	?	70
TSO	Capacity	\$3,000 - \$7,000	\$300 - \$700	?
	A/S Regulation	\$5,000 - \$18,000	\$500 - \$1,800	8760 (or bid 24*n)
	A/S Spinning Reserves	\$2,500 - \$4,000	\$250 - \$400	8760 (or subset)

Figure 2: Estimated Full Value Stack for V2G [17]

4. In 2021, a broad meta-analysis of 340 V2G cases identified two V2G applications as generating the greatest economic benefits: load leveling, where electricity is returned to the grid to reduce load peaks to avoid damage to grid infrastructure, and participation in the secondary frequency market, which covers medium-term frequency control [18]. These services were assessed to have the highest value even when accounting for battery degradation costs. The paper also mentioned energy trading value but determined this activity to be price arbitrage that does not provide a distinct grid service.

Taken together, these reports suggest that V2G compensation should account for the values of energy, ancillary services, and capacity, as well as infrastructure deferral. Further study will be essential to prove out the realization of these specific grid and system services.

2.1.2 V2G Rates can Drive Equity Outcomes

By improving the economics of electrification in certain vehicle segments, such as school buses, revenues from V2G can deliver outsize health and economic benefits for the underserved and low-income communities that often live near vehicle yards and along transportation routes. Additionally, V2G services like peak shaving will not only reduce overall energy system costs but may also reduce the need for grid operators to deploy costly and polluting peaker plants to meet peak system demand.

2.1.3 Precedent for V2G Rates and Projects

To date there are limited examples of rates designed specifically to fit this application, but several V2G rates are being developed via pilot programs across the United States as well as in Denmark [15], the United Kingdom [19], and Japan [20].

1. An early compensation mechanism for vehicle energy delivered back to the grid was established by a 2010 law in the state of Delaware that included V2G under the state's prevailing net energy metering (NEM) policy [21]. Under this policy, any energy provided by a customer back to the grid is credited to the customer's account at the same rate (price) as the customer originally paid to charge the vehicle battery. Any excess credits accrued can be applied to the customer's future bills within an annual billing cycle, but excess credit value at the end of the cycle reverts to the utility [22].
2. SDG&E has submitted an application to offer a V2G rate for commercial vehicles [23]. SDG&E's Commercial Electric Vehicle Dynamic Rate is a V2G-Export rate based on two factors: (1) a time varying component of the rate that values the energy and (2) a Peak Energy Payments capacity payment. This program would only be open to customers with Schedule EV-HP and is still pending approval.
3. PG&E was authorized to initiate commercial and residential pilot programs for EV exports to the grid [24]. The programs will assess five value-streams: backup power, customer bill management, system real-time energy, system renewable integration, and grid services (such as system resource adequacy, system capacity). Customers will have the option of selecting a static TOU rate or a dynamic rate and are offered a $3,000 to $5,000 one-time incentive to encourage pilot participation.
4. A settlement between PG&E and key parties was approved by the CPUC in October 2022, establishing an export compensation rate pilot for commercial customers [25]. The pilot presents a new, dynamic rate that would be comprised of a marginal energy credit and a marginal generation capacity credit. While the rate itself is strictly cost-based export compensation, an additional one-time early participation incentive ranging from $1,800 to $6,560 was also approved to encourage commercial EV operators to join the pilot.
5. NV Energy has initiated a School Bus V2G Trial to assess the potential for provision of grid services including system peak shaving and renewables integration on the distribution grid [26, 27]. The program would compensate for energy delivered back to the grid at the lesser of either the hourly system incremental generation cost or the utility's average hourly Load Aggregation Point price. In addition, the program provides an incentive when the bus is delivered in the amount of $0.60 per watt-hour of bus battery capacity and a $600 per charger per year operations and maintenance incentive.
6. The New Hampshire Electric Co-op has announced plans to offer a transactive energy rate, which would send customers an hourly price signal of the same amount for either consumption or export to the grid [28]. An initial trial of the rate in a V2G context is underway using Nissan Leafs at Plymouth State University.

2.2 Models for V2G Rate Structures

Many utilities offer rates or programs that, while not designed particularly with V2G in mind, may provide avenues for V2G compensation and can serve as models for broader deployment. Three main models that we have identified are: demand response programs, feed-in-tariffs, and standardized export pricing.

2.2.1 Demand Response Programs

Many demand response programs, designed to address events when the grid is capacity constrained, are frameworks under which V2G could be compensated for delivering supply to the grid. Most of these are envisioned with flexible building loads or behind-the-meter storage in mind; nonetheless demand response programs are well-suited to accommodate V2G and are the basis for compensation in most V2G pilots to-date.

1. California's Emergency Load Reduction Program (ELRP) is designed to avoid forced outages during summer grid emergencies [29]. Recently, ELRP has also been identified as a mechanism through which to pilot V2G. In July 2022, the El Cajon School District, technology provider Nuvve, and SDG&E announced an electric school bus V2G pilot that includes eight 60 kW chargers to be operated over five years and compensated for export to the grid at the SDG&E ELRP rate of $2 per kilowatt-hour [30, 31].
2. Another notable example is Massachusetts's National Grid's Connected Solutions Daily Dispatch program, which is aimed at any technology, such as batteries or thermal storage, that can help reduce electric grid loads [32] National Grid offers up to $200 per kW of energy discharged during 2-3 hour-long events during the summer where customers are notified a day in advance. Over the summer of 2022, a deployment of electric school buses participating in this program responded to 32 event signals and delivered over seven MWhs of electricity back to the grid over 80 hours [33, 34].

Considerations for applying demand response programs to the V2G context highlight challenges for and the potential of this mechanism. First, technology or performance requirements for participation in demand response programs may not be well-suited to EV capabilities. While EV batteries should be relatively responsive to signals and quick to bring online when called, their first and foremost duty is in their capacity as transportation assets; thus, EVs may not be readily or reliably available for demand response compared to other technologies deployed solely for the purpose of providing grid services. For example, school and transit buses may be responsible for providing transportation during emergencies, so to the extent that critical grid events are correlated with emergency events (such as extreme heat events, fires, etc.), those EVs may not be available to provide grid services. A V2G compensation regime based on a demand response program might require EV-specific design components in order for EV operators to justify the investments required to enable V2G-capabilities.

Another consideration is that the value of a specific grid service may decline on the margin as more of that service is provided at a particular time and location on the grid. While the first few vehicles' worth of V2G capacity provided by a fleet at its depot could be of high value to the utility at that site, the value of the 100th vehicle providing V2G at the yard may well be much lower. The potential for diminishing marginal value of additional capacity is common across storage and demand response assets, but EVs are unique in their locational flexibility. Within the operational constraints of their primary duties as transportation assets, it is possible that EVs could create extraordinary grid value by providing V2G services at locations on the grid with greatest need during a particular event. Program designers and V2G implementers that can capture and leverage the mobile nature of EVs as grid assets may be able to create exceptional value through demand response programs.

2.2.2 Feed-in-Tariffs

Another model is the feed-in-tariff (FIT), where customers who own a particular eligible technology, such as rooftop solar, are compensated by the utility for the amount of energy they produce and provide to the grid at above-market prices. FIT programs that compensate for energy storage in batteries are especially well suited to compensate for V2G that provides energy or capacity back to the grid. This is reflected in the short-term policy recommendations of the Working Group, which suggest that V2G be made eligible for various stationary storage pilots and incentives [16].

1. In 2021, Los Angeles Department of Water and Power expanded its existing FIT program to include solar projects that are paired with battery energy storage [35]. The long-term contracts bid out under the program are limited to "Preferred Zones of Development" where the grid value

is anticipated to be highest, likely reflecting the same values of energy, capacity, and infrastructure deferral that V2G may provide.

A key consideration for applying FITs to the V2G context is that FITs are generally conceived to be temporary policy levers installed to boost an early-stage technology or category of deployment by supplementing or enhancing market rate compensation. While FITs can provide a valuable runway for new technologies, they are uncommon in mature markets. As a mechanism for V2G compensation, FITs might constitute a near-term approach to encouraging deployment but would not seem to obviate the need for establishing pathways for V2G compensation for delivery of specific grid services at their true market value.

2.2.3 Standardized Export Pricing and Net Energy Metering

The final model is an expansive category that includes programs and rates available to utility customers that participate as both producers and consumers on the electricity grid. Many standardized export price regimes were established following the passage of the Public Utility Regulatory Policies Act of 1978 (PURPA) that enables qualifying facilities to sell energy and capacity and purchase services from the grid. These technology neutral rates and programs generally compensate exports to the grid at market or at pre-determined prices (e.g., avoided cost). A similar model is NEM, which is a metering and billing framework that enables compensation for generators on the distribution grid, typically limited to particular eligible technologies. Though it is unclear whether EVs or aggregations of EVs are eligible under most current program requirements, the compensation structures in these schedules generally parallel the potential V2G grid values discussed above.

1. A FERC decision in March 2021 affirmed that battery storage can be included in projects as qualifying facilities under PURPA [36]. There is also precedent for FERC revising regulations to account for technology evolution, such as its 2020 revisions to sections 201 and 210 to encompass fuel cell systems as a type of qualifying cogeneration facility [37].
2. The 2021 Infrastructure Investment and Jobs Act further promotes V2G through amendment to PURPA section 111(d) requiring cooperatives, municipal utilities, and state regulators to consider adopting standards that enable demand response, demand flexibility, and increased EV charging [38]. PURPA Section 292 details that standardized rates must be set for qualifying facilities of less than 100 kW in size [39]. Further, these rates should reflect marginal energy prices, capacity costs, and avoided costs to the utility including deferred expansion costs and fossil fuel reductions – all value streams that have been identified as potential services V2G can provide.
3. As noted above, the state of Delaware explicitly includes V2G energy under the state's prevailing NEM policy. However, a 2022 amendment to the policy eliminated the opportunity for payouts to customers for excess credits accrued, preventing V2G operators from generating revenues from provision of energy beyond the offsetting of their utility bill.

Something to consider when assessing the opportunity to apply standardized export pricing to the V2G context is that, increasingly, generators on both the transmission and distribution systems are integrating complementary technologies (such as solar and storage). The technology-neutral nature of standardized export prices makes these an attractive compensation regime for V2G because they more flexible to the diversity of resource types that might be integrated alongside a V2G deployment. On the other hand, the market value of V2G energy, capacity, or avoided cost may be insufficient to justify the upgrades necessary to facilitate V2G. Additional societal value streams that V2G can drive or enable, such as resilience, greenhouse gas emission reductions, and avoided air pollution are often not compensated or compensated sufficiently within traditional energy markets, resulting in a potential undersupply of V2G relative to its true potential from a societal value perspective.

In contrast, NEM compensation regimes tend to be technology-specific and are generally founded on technology-specific assessments of grid or societal value. This technology-specific compensation structure mitigates the value stream issue noted above but may not lend itself well to situations where V2G is part of a diverse, multi-asset deployment.

3. Path Forward: Design Recommendations for Effective V2G Rates

To date, there is limited experience with implementation of V2G rates, so it is challenging to draw definitive lessons from existing rate structures. Furthermore, V2G has largely been implemented through pilot programs that include supplemental elements and incentives in addition to rate mechanisms. Nonetheless, V2G capability is coming quickly as more vehicles on the market include the capability to send power back to the grid. Nissan, an early entrant, will be joined shortly by Ford and Volkswagen, each of which are rolling out new V2G-capable vehicles [40, 41]. More than a dozen utilities are piloting electric school bus V2G capabilities [42]. As the technology gains traction, appropriate rate design will become important to take advantage of potential grid benefits and drive cost-effective deployment of V2G technology.

Currently, markets provide compensation for individual grid services based on the time- and locationally-specific values of these services. While it would be ideal to avoid technology- and customer-specific rates, utility rates may need to be designed to provide different levels of compensation depending on the type and magnitude of grid services provided by V2G. Rates should be designed to be flexible with changing grid needs to appropriately encourage V2G to provide grid services when and where it is valuable to do so. This is in notable contrast to offering an overarching fixed tariff, such as a FIT. Simpler approaches may be to encourage vehicle-to-building deployments that smooth site load and offset demand on the system at peak times. Such mechanisms can be implemented readily.

Vehicle aggregations are likely to be the most cost-effective approach to providing substantial power or grid services. To contribute to addressing grid needs at scale, grid operators need certainty that the energy and services will be sufficiently provided when called upon. As V2G is scaled, mechanisms to guarantee provision of power or grid services, such as penalties, may be needed.

To effectively encourage the provision of V2G services, rates and programs will need to offset the incremental investments necessary to enable V2G participation, including in customer equipment, communications technology, and energy management and control platforms, as well as incremental costs incurred through V2G participation – notably battery degradation. When V2G technology is mature and has reached scale, these investments and costs should be fully recuperated through cost-reflective rates. In the meantime, as exemplified by the participation incentives included in the two PG&E V2G compensation pilots, additional subsidies that offset these upfront costs may be necessary to encourage adoption of the technology.

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