Evaluating California's Vehicle-Grid Integration Opportunities

A Framing Document

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GRIDWORKS

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Introduction

Today California leads the nation in electric vehicle adoption with over 600,000 on the road,[1] supported by about 20,000 public charging ports and associated investment in the underlying grid infrastructure. To realize its vision of a carbon-free economy, California has set a target of 5 million zero-emission vehicles on the road by 2030 and 250,000 charging ports in service by 2030.[2]

Fueling millions of electric vehicles (EV) is both a challenge and an opportunity for California's grid and customers. The California Independent System Operator, California Energy Commission, California Air Resources Board, and California Public Utilities Commission (together "CA State Agencies") have each invested significant effort to investigate how electric vehicles can be best planned for and best integrate with the electric grid.[3]

One key focus of the CA State Agencies has been to understand the most valuable opportunities for integrating EVs with the grid and determining what that value is. For example, early projections of electric vehicle load by E3 show up to 4.9 GW of peak incremental load at the California system level by 2030.[4] Figure 1 below shows a forecast of unmanaged EV charging load shapes in California based on vehicle types, charging level and location and driving patterns.

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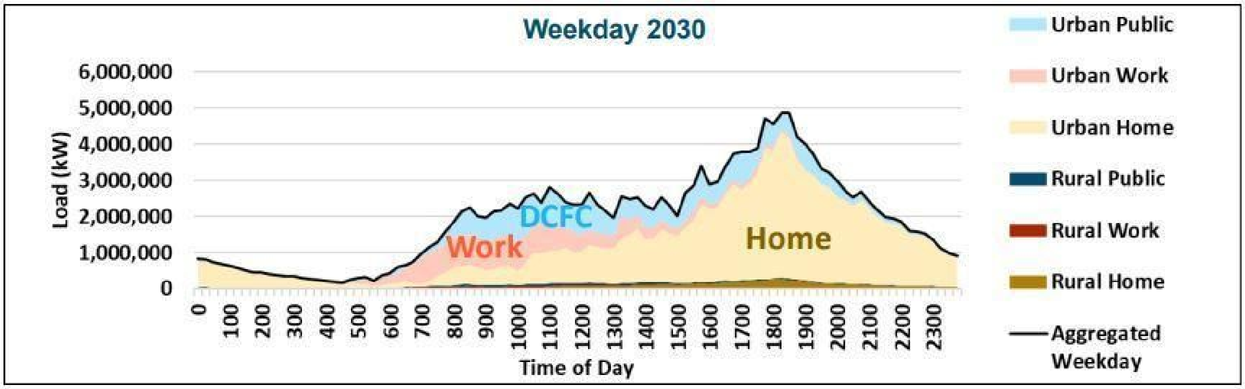
[1] http://www.veloz.org/california-sells-its-500th-electric-car/
[2] Executive Order B-48-18
[3] https://www.caiso.com/Documents/Vehicle-GridIntegrationRoadmap.pdf
https://ww2.energy.ca.gov/transportation/vehicle-grid-integration/
https://www.cpuc.ca.gov/vgi/
[4] Cutter, Eric (E3). "California Framework for Grid Value of Vehicle Grid Integration" April, 2019.
https://gridworks.org/wp-content/uploads/2019/05/VGI_4.12-Slides.pdf



If charging occurs during existing peak periods, California may (1) need to invest in new distribution infrastructure, (2) face new grid operational challenges, and (3) see increased emissions from the electric sector. Furthermore, left unmanaged, EV load could introduce new peaks. Inversely, avoiding this peak and instead charging during times that are optimal to both the customer and the grid presents an opportunity. If electric vehicle load can be managed or vehicles can be configured to export power to the grid, new investment, operational challenges and emission increases can be avoided, all while reducing emissions from the transportation sector and providing new, more affordable mobility.

Gridworks calls this opportunity Vehicle Grid Integration (VGI). VGI can include a range of solutions, from passive interventions such as electric time-of-use rates which give customers pricing signals to incentivize or disincentivize charging during specific time windows, to active solutions that directly modulate the vehicle's charge or discharge into the grid. As detailed herein, VGI may be able to provide a wide range of benefits, including to the customers, electricity ratepayers, their electricity service providers, grid operators and the overall environment and society.

However, significant challenges remain in understanding the value of VGI, as well as the best means and strategies to capture that value. Challenges include understanding the costs of achieving VGI, engaging customers in VGI programs, and organizing the data needed to analyze and pursue VGI.

To date, evaluations of VGI opportunities have focused on the benefits of VGI, without looking at the costs. This benefits-only valuation approach has been a powerful first step to identify the potential promise of VGI, but without understanding the costs, the industry cannot understand the net benefit of VGI, and it may be hard to move forward with potential cost-effective and scalable VGI solutions. Some fundamental questions, including whether it is more cost-effective to prepare for EV load using traditional infrastructure upgrades versus VGI techniques remains unanswered for a wide range of use-cases.

Another important challenge is engaging customers. At present it is unknown if and to what extent EV customers will enroll and participate in VGI programs. Electric vehicles remain first and foremost a means of transport for customers. Their willingness to think of and use their vehicle to pursue cost savings or societal benefits is not a foregone conclusion.

Finally, to date modeling VGI value has been plagued by a lack of organized, easily accessible and available data. As a result, valuation assessments have incorporated a nontrivial amount of uncertainty. Finally, past studies on VGI value have used different valuation frameworks and terms, making it difficult to compare across results, and harder for the industry to communicate effectively.

To further pursuit of the benefits of VGI and address these challenges, Gridworks launched a VGI Initiative in 2018. Building on the work of California State Agencies and a 2017 VGI Working Group, the Initiative began with a series of expert interviews and a review of relevant literature exploring the potential value of VGI, as well as the current barriers to realizing that value. These insights then fed into a series of workshops with VGI thought-leaders, including representatives of California's energy agencies, utilities, automakers, charging network providers, environmental and consumer advocates, and consultants. These workshops focused on developing a method by which the value of VGI could be assessed, barriers better understood, and solutions identified. A summary of the insights gained through the four VGI Initiative Workshops and participants is provided in Appendix A. This paper shares the results of the literature review, expert interviews, and workshops, which amount to a recommended VGI Opportunity Evaluation Method that aims to serve California immediately but could also be adapted for other states.

This document:

- summarizes the potential grid benefits of VGI;
- compiles expert perspective and experiences on VGI's value and barriers;
- suggests a step-by-step methodology for evaluating potential VGI use cases, including an approach to sequencing the inquiry and data needs;
- Identifies outstanding questions and next steps in anticipation of upcoming VGI regulatory efforts.

Defining VGI and its Potential Grid Benefits

Definition

For purposes of this Framing Document, we rely on California's SB676, which defines VGI as follows:

> *"Electric vehicle grid integration" means any method of altering the time, charging level, or location at which grid-connected electric vehicles charge or discharge, in a manner that optimizes plug-in electric vehicle interaction with the electrical grid and provides net benefits to ratepayers by doing any of the following: (A) Increasing electrical grid asset utilization; (B) Avoiding otherwise necessary distribution infrastructure upgrades; (C) Integrating renewable energy resources; (D) Reducing the*

cost of electricity supply; (E) Offering reliability services consistent with Section 380 or the Independent System Operator tariff"[5]

VGI includes both managed charging and demand-response use cases (V1G), as well as use cases in which vehicle batteries discharge stored power back onto the grid (V2G).

Benefits

In 2017, California's State Agencies established a VGI Working Group (2017 Working Group), which created a draft VGI Benefits Framework.[6] That framework merged more than twelve alternative valuation frameworks to organize a detailed stack of benefits of VGI. Figure 2 shows their results:

[5] SB676 as of August 12 (http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB676)

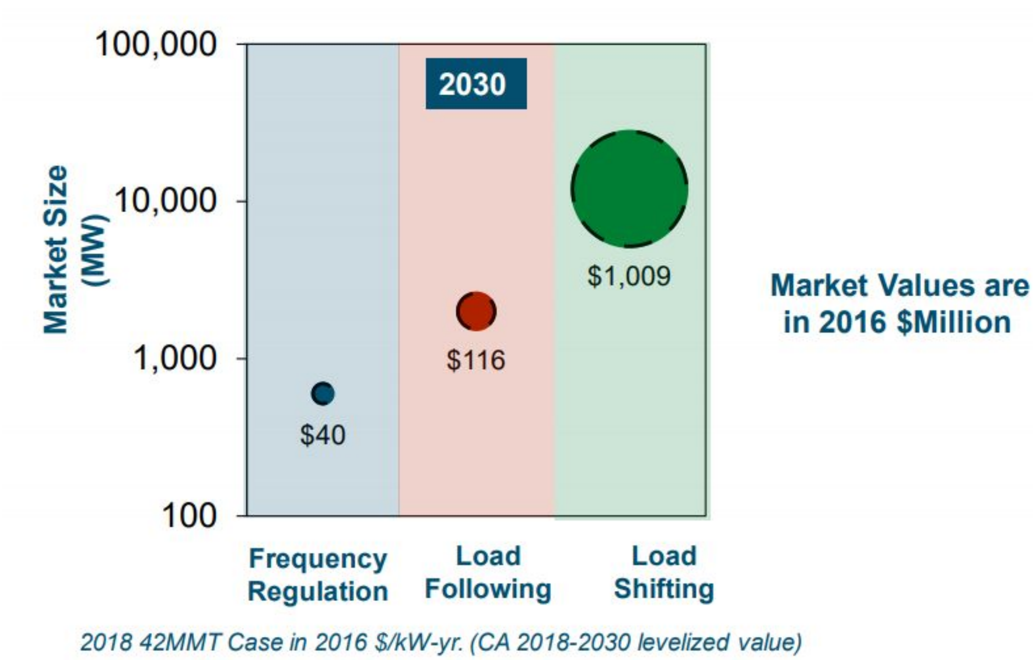
[6] "VGI Use Case Sub Group Final Report" California Public Utilities Commission. July 2018. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442454524

Figure 2: 2017 Working Group VGI Benefits Framework, Updated by Gridworks

Beneficiary	Benefit
Customer	TOU Bill Management
	Demand Charge Management
	Increased PV Self Consumption
	Back-up Power
	Power Quality
	ME&O regarding Bill Savings, Charging and EV Options (business customers)
	Low Carbon Fuel Standard Credits (LCFS)
Distribution Company	Distribution Capacity/Deferral
	Reliability (back-tie) services
	Voltage Support
	Resiliency/microgrid/islanding
IOU/CCA	Storage Mandate Compliance
Transmission Owner	Transmission Capacity/deferral
	Black Start
	Voltage Support
	Inertia Primary Frequency Response
Wholesale Market	Frequency Regulation
	Reactive Power Support
	Spinning Reserve
	Non-spinning Reserve
	Replacement Reserve
	Day Ahead Energy
	Real Time/Imbalance Energy
	Renewable Integration
Resource Adequacy	System Capacity
	Local Capacity
	Flexible Capacity
Societal & Environmental	GHG Reductions
	Local Pollutants
	Economic Growth

This benefit stack in Figure 2 represents many of the potential benefits VGI can yield. Focusing exclusively on grid benefits (and not the costs of realizing those benefits), recent modeling by E3 suggests the annual benefits of Load Shift could total $1.1 billion by 2030, driven in part by higher penetrations of solar generation.[7] Load Shift, of which VGI may be a major source, means enabling and incentivizing customers to meet their electricity needs ("take") during periods of surplus generation, lower energy prices, and lower emissions, while reducing their consumption ("shed") during periods of scarcity and higher emissions.[8] Figure 3 below shows the market size for Load Shift, as well as two ancillary services, frequency regulation and load following.

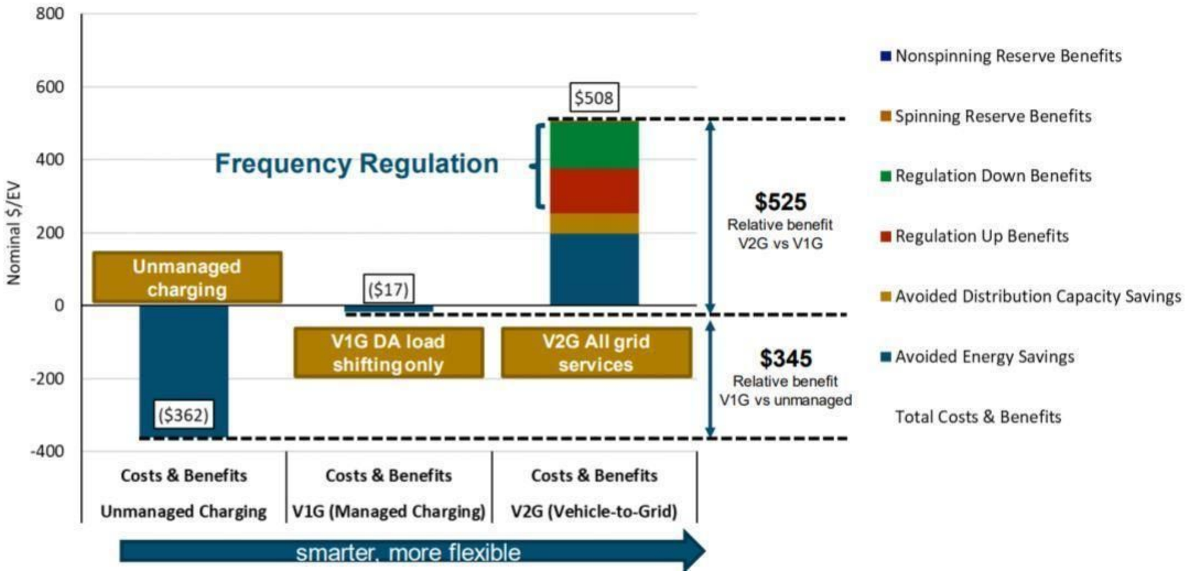
Figure 3: Relative Size of Wholesale Markets in 2030 based on CPUC Integrated Resource Planning Scenarios



The benefits of VGI solutions through managed EV charging and bi-directional power flows, can theoretically reduce both grid capital investments and operating costs by reducing the amount of storage capacity built, renewable curtailment and ancillary services from other sources. Compared to unmanaged charging, the same aforementioned study estimates potential benefits of V2G could be as high as $620/EV-yr. V2G provides incremental benefits of $275/EV-yr over V1G, which in turn provides benefits of $345 over unmanaged charging (Figure 4).

[7] Gridworks VGI workshop"Transportation Energy Demand Forecast" California Energy Commission. April, 20198. https://gridworks.org/wp-content/uploads/2019/05/VGI_4.12-Slides.pdf
[8] "Final Report of the California Public Utility Commission's Load Shift Working Group." January 2019.

Figure 4: Incremental Value of V2G over V1G and Unmanaged Charging for BEV In 2025



Assessing Value in California

California's approach to assessing the value of VGI may be informed by how it has assessed the value of other resources. For over three decades the CPUC and CEC been national leaders in developing methods to calculate the 'avoided costs' of and perform cost-benefit analysis for distributed energy resources (DERs). California's Standard Practice Manual, first published in 2001 set the standard for cost-effectiveness tests of DER that has been implemented in over forty states. In turning to the value of VGI, California agencies are once again treading into new territory that may require leveraging, and perhaps updating, methods for DER benefit-cost analysis and potentially set an example for other states to follow.

The traditional method for valuing DER in California has relied on avoided costs that are approved by the CPUC. Hourly avoided costs are calculated for each of 16 climate zones and paired with the hourly load shapes or grid impacts calculated for DER such as energy efficiency or energy storage. The CPUC Avoided Costs were most-recently used in a cost-effectiveness evaluation of energy storage for the Self-Generation Incentive Program to be released by the CPUC in August 2019. These avoided costs are used with optimal dispatch modeling to produce the incremental value of V1G and V2G in Figure 4. Per CPUC Decision 19-05-019, a minor update of the avoided costs will be issued in August 2019 with a major revision and update scheduled for April 2020 (R. 14-10-003). In scope for the major April 2020 update is consideration of how to better and more fully value flexible resources like energy storage and electric vehicles and the grid services they can provide.

The CPUC Integrated Resource Plan (IRP) Proceeding (R. 16-02-007) is the umbrella planning proceeding to consider electric procurement policies and programs and a key venue for implementing SB 350. The IRP includes capacity expansion and production cost modeling to compare the total capital and operating costs of different resource planning scenarios, including portfolios with more flexible DER. For example, sensitivity analysis in 2017 of a scenario with flexible EVs found incremental cost savings of $107 million per year relative to the 42 Million Metric Ton (MMT) Reference System Plan.[9] The IRP reference system plan assumptions and modeling approach were used to develop the illustrative estimates of the grid value of VGI presented in Figure 3. In 2020, the 2019-20 IRP Cycle will conclude and the 2021-22 IRP cycle will be initiated. Analysis of resource portfolios that include VGI in the IRP could provide quantitative estimates of the resulting cost savings.

Both the CPUC Avoided Costs and the CPUC IRP modeling would present two possible alternatives to quantifying the value of VGI for the state of California, which may then be used to determine the VGI programs and services that provide net benefits from a policy perspective. Additional modeling would be required to quantify the benefits that could be monetized and translated into revenues for automakers, EVSPs, aggregators and customers to evaluate specific business cases. One example of such an analysis is the aforementioned SGIP energy storage cost-effectiveness analysis due out in August 2019, which calculates the customer bill savings realized with behind-the-meter energy storage for a variety of customer types, retail rates and system configurations.

Current Literature and Expert Perspective on the Value of VGI

To update and add additional detail to the benefit stack developed by the 2017 VGI Working Group, Gridworks reviewed the major recent studies of potential VGI value and interviewed expert stakeholders. A summary of key findings from these efforts is provided below.

Literature Review on the Value of VGI

The literature review included work led by electric utilities, automakers, universities and national laboratories, and other VGI stakeholder and research organizations.[10] Gridworks observes that VGI investigations have recently moved from initial “paper studies” to real-world types of demonstration and pilot projects. These have now included both individual site studies as well as larger utility programs involving dozens or even hundreds of vehicles. These studies provide an invaluable starting point to yield better information about actual use cases for VGI, more realistic assessments of potential value streams, and more refined estimates of benefits and costs, as described below.

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[9] CPUC Proposed Reference System Plan Presentation, September 19, 2017.
[10] “Vehicle-Grid Integration Value Study Literature Review Summary” Gridworks. March, 2018.

With regards to the benefits of VGI, the literature features examples of V1G and V2G service to EV drivers and fleet owners, utility distribution companies, wholesale markets, and participants along the value chain such as grid service aggregation and scheduling coordinators.

Los Angeles Air Force Base Vehicle-to-Grid Demonstration

A significant demonstration has taken place over the last several years at a Los Angeles Air Force Base facility with support from a combination of agencies including U.S. DOE, U.S. DOD, and the California Energy Commission. This demonstration focused on the economic viability of using EV of V2G activity (demand side management and participation in wholesale markets). Takeaways from the demonstration include:

- Demonstration used a 15-vehicle fleet with a range of battery sizes, leading to a range of results.
- Frequency response gross revenues for the 15-vehicle fleet were $400-1,100 per month ($25-72 per vehicle per month) but net benefits including CAISO and scheduling fees were positive in only one month out of 10 studied. Typical net losses were a few hundred dollars lost in the other months (range of $200 to $600 per month) for this small example fleet.
- Larger fleets may generate more net revenue as they spread out monthly fixed costs over more vehicles, but this is not assured.
- At the end of the pilot, the DOD decided to discontinue this effort due to the notable lack of economic viability.

SmartCharge

Next, a SmartCharge project led by Honda and eMotorWorks and in conjunction with Southern California Edison has recently focused on DR potential from VGI as well as investigations of renewable power acceptance at key times for the grid. The study details include:[11][12]

- Project included a 6-month residential DR and renewable power acceptance study with SCE.
- 60 Honda FIT EV drivers (company employees) were included in the study.
- For compensation, $50 is provided to each individual to participate, then $50 every two months for following the program's charge schedule guidance.
- Project used 10-day baseline and then Green Button and OEM Telematics data for monthly data reporting.
- Tracked load reduction/consumption, incentives, etc.
- 100 kW bid capacity at $10/kW.

Analysis of V2G Opportunities Across Various ISO Territories

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[11] "Open Vehicle Grid Integration Platform: Phase 2 Updates OEM Perspective" Honda R&D Americas, Inc. March 2018.

[12] "eMotorWerks, Honda, & Southern California Edison Offer Nation's 1st Smart Charging Program" CleanTechnica. February 2018. https://cleantechnica.com/2018/08/02/emotorwerks-honda-southern-california-edison-offer-nations-first-smart-charging-program/

An analytical study examined the value of frequency response services, including economics as well as avoided GHG emissions, for V2G-based frequency regulations across various ISO territories. The study included the following features and key findings:[13]

- Focus on frequency response net revenue analysis across ISO areas
- Results include findings for GHG savings and net revenues
- Net revenue analysis included for 5 ISO regions
- Highest revenues were found to be in NYISO at up to about $42,000 (central case) per vehicle over a 16-year period (undiscounted) followed by PJM ($38,000), CAISO ($27,000), ERCOT ($26,000), and then ISO-NE ($18,000)
- Some regions have relatively higher potential revenue per vehicle but others have higher total revenue potential because they are larger EV markets

There have also been a series of "utility scale" VGI projects in recent years, typically led by utility groups as next-step VGI pilot projects to use VGI to address distribution-level grid considerations. In California, SDG&E, PG&E and SCE also have active pilot studies and analysis efforts.

SDG&E Plug-in EV TOU Pricing and Technology Study

SDG&E was exploring VGI and EV load shift concepts in a 2012-2013 study with data that was analyzed by a research team.[14] Key elements and findings of this study included:

- Calculation of elasticities of demand for shifting EV charging load based on utility prices.
- Examined SDG&E programs that included three different experimental rate designs, with higher/lower on-peak and off-peak prices, for about 100 test households that were EV owners.
- EV drivers exhibited learning/behavior changes and were most responsive to price signals around on-peak and off-peak rates, shifting their demand from some on-peak to more off-peak times during the study.

SDG&E Power Your Drive

More recently, SDG&E has been pursuing the "Power Your Drive" (PYD) program. This innovative real-world project to send EV drivers information on the next days' charging rates that vary on an hour-by-hour basis. This allows them to schedule their charging demand, shift charging to avoid higher priced periods. Key features of the program include:[15]

- 2900 energized ports at 239 sites (as of May 2019)
- 238 site agreements and 932 included charge ports as of September 2018.
- Participants receive hourly prices for charging on a day-ahead basis.

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[13] "Light-duty electric vehicles to improve the integrity of the electricity grid through Vehicle-to-Grid technology: Analysis of regional net revenue and emissions savings" David B. Richardson. March 2013.

[14] "Final Evaluation for San Diego Gas & Electric's Plug- in Electric Vehicle TOU Pricing and Technology Study" Nexant. 2014.

[15] "Semi-Annual Report, Electric Vehicle-Grid Integrated Pilot Program (Power Your Drive)" San Diego Gas and Electric Co. 2018.

- 87% of charging from Power Your Drive Participants occurring during off-peak hours, compared to 81% off-peak from EVTOU residential customers and 77% DR customers[16]
- Observed response appears to be both load-shifting of PEV charging within a day along with potential shifts across days.

PG&E'S Electric Vehicle Smart Charging Pilot

PG&E and BMW partnered to "demonstrate the technical feasibility and grid value of managed charging of electric vehicles, as a flexible and controllable grid resource." The pilot spanned several VGI use-cases over its two phases.[17]

- Phase 1 focused on demand response and load curtailment, with 96 participating EVs. To minimize disruptions, second-life stationary battery storage (100 kW/225 kWh) was used to fill any load gaps for the required 100 kW of DR capacity. During the 18-month trial, the EVs responded to 209 DR events, and they met the performance requirements for 90% of those events, with an average contribution of 20% from the vehicles and 80% from the 2nd life battery system.
- Building on the successful partnership between the utility and the auto manufacture, Phase 2 expanded the list of tested use-cases, focusing on: (1) maximizing renewable energy intake, while managing customer bill; (2) accounting for residential & away-from-home charging; (3) offering DR grid services for load-curtailment and load-increase, at the system-level and distribution-level. The pilot expanded to 350 participants and used BMW proprietary aggregation software and telematics.
- During Earth Week, 47 vehicles received more than 50% of their energy during the day, doubling the number from the week prior.

Pilot also demonstrated how vehicle drivers can shift vehicle charging into times when excess renewable energy – primarily solar and wind generation – can be absorbed and stored in the vehicles.[18]

JUMPSmart Maui

Another utility-scale project that has been ongoing for some years and is now starting to yield initial findings is the JUMPSmart Maui project, led by Hitachi and with financial support from NEDO in Japan and participations from Hawaii government agencies and universities. The

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16 https://www.sdge.com/sites/default/files/regulatory/March%202019%20PYD%20Report%20Final_0.pdf

17 Pacific Gas & Electric, 2017, BMW i ChargeForward: PG&E's Electric Vehicle Smart Charging Pilot. https://efiling.energy.ca.gov/GetDocument.aspx?tn=221489.

18 Valerie Nibler & Robert W. Anderson. Vehicle-Renewable Integration Report for BMW Total Charge Management: Optimizing Electric Vehicle Charging using Renewable Energy Excess Supply. https://olivineinc.com/2019/04/11/report-on-vehicle-renewable-integration-for-bmw-of-north-america/

project started in 2011 and continued through 2016, with two project phases. Key features of the initial project include:[19]

- Demonstration project examines ability of V2H and V2G concepts to mitigate “duck curve” shape and establishes Maui Virtual Power Plant concept for controlled PEV charging.
- Initial project focused on installing DCFC as a supplement to residential charging on Maui.
- Project Phase 2 is yielding more information about grid values especially for new V2G use cases:[20]
  - DCFC program involves 306 of 889 EVs on Maui.
  - 200 households are in Level 2 V1G charger program.
  - 80 households were in the project Phase 2 V2G pilot program – using Hitachi bi-directional chargers and using IEEE 2030.5/SEP 2.0 for control.
  - Study showed significant ability to shift EV charge load from peak times from 5-8pm to early morning hours.
- Based on charging habits of 80 participants, 14-31% of the total capacity of the EV batteries was available to discharge during peak hours (V2G), 8-30% of the capacity was available during night time charging, 2-4% was available during daytime charging, and 6-16% was available for discharge in the early afternoon (V2G), based on when vehicles are connected and their state-of-charge during those periods.

Study of EVs as an Alternative to Stationary Battery Storage

An analytical study was conducted to examine the potential of EVs to substitute for stationary battery storage for the California grid. The study focused on various cases where EVs could offer power support on the GW scale. Key findings of the study include:[21]

- V1G value scenario provides gross value equivalent to $1.45-1.75 billion of stationary power storage with 1.0 GW of daytime over-generation and evening ramping power support (each)
- Estimated cost of V1G service for 1.0 GW is $150 million, yielding a net value range of $1.3-1.6 billion.
- with V2G capability by 2025, gross value increases to the equivalent of $12.8 to $15.4 billion of stationary storage or – 5.0 GW of power capacity, which is much more than the ~1.3 GW state mandate

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[19] “Smart Community Case Study: International Projects for Increasing the Efficient Use of Energy / Japan US Island Grid Demonstration Project in Hawaii (FY2011 - FY2016) Final Report” NEDO. 2017. https://www.nedo.go.jp/content/100864936.pdf
[20] “Vehicle-Grid Integration Demonstration in Maui: JUMPSmartMaui Project” Hitachi Ltd. 2018.
[21] “Clean vehicles as an enabler for a clean electricity grid” Jonathan Coignard, Samveg Saxena, Jeffery Greenblatt, and Dai Wang. 2018.

- Note that study assumes stationary battery storage at $500/kWh whereas these costs may be considerably less in near future, so the values above could be somewhat overstated

Various V1G and V2G concept value studies have been conducted including both conceptual studies and a growing number of real-world studies that are yielding a more nuanced understanding of VGI values that can actually be realized. Projected net revenue values are highly variable by VGI use case and application, but are positive in many cases suggesting that as more streamlined approaches to monetize VGI services in the marketplace, sustainable business models around these services appear to be possible.

Expert Perspectives on the Value of VGI

The views related to the VGI value proposition expressed by the experts interviewed[22] varied both among and within the four stakeholder groups, as noted below, but first some overall key themes were apparent across all of the groups.[23] These overall themes include:

- the important concept that VGI value estimations must now focus on overall net value (i.e. both benefits and costs) for each use case rather than gross revenues as have mainly been the focus in the past, and as some VGI schemes entail significant sunk and variable costs and different benefits and costs for each market player (e.g. driver, network operator, utility, etc.);
- near-term opportunity to explore the basic V1G solution focuses on: EV charging cost reduction to EV drivers, workplaces, and fleets, through active or passive managed charging that achieves demand charge reduction and flexible load adaptation to TOU rates, as well as pilot VGI rates;
- the evolving "duck curve" in California represents a set of emerging opportunities for VGI, with both load reduction and grid-service opportunities during the evening ramp, as well as with load increase and valley-filling opportunities at other times to absorb low-cost and low-carbon renewables that may otherwise by curtailed;
- new developments in the California Low Carbon Fuel Standard program that award incremental electricity-sector credits for utilizing V1G to time EV charging with periods of lower-than-average grid carbon intensity are an important emerging opportunity; and
- alignment among, as well as a clear value proposition for, the various groups of actors involved in a VGI offering is important to ensure the successful performance of VGI business models.

With regard to the views expressed by the four stakeholder groups:

[22] See Appendix E for a complete list of experts interviewed
[23] "Vehicle-Grid Integration Initiative: Expert Interview Summary" Gridworks. March 2018. https://gridworks.org/wp-content/uploads/2019/03/VGI-WG-Expert-Interview-Summary-final.pdf

- the electric utility group was unanimous in saying that one of the best near-term opportunities was to take advantage of their latest rate structures to manage charging for site electricity cost reduction. Some interviewees suggested indirect tools have a lot of value. For example, some individual residential EV customers could achieve significant annual savings compared to gasoline by taking advantage of the default or the best rates and cheapest adequate charging infrastructure solutions. Some larger fleet and electrified transit organizations could also achieve significant annual savings compared to gasoline or diesel by taking advantage of rate structures and managing their demand, depending on the size of the fleet and details of their flexible load characteristics. Further study is required to determine additional potential savings under managed charging.
- The automotive companies tended to also indicate that smart charging/V1G was the clear near-term opportunity with low implementation cost and difficulty, but both mentioned V2G as well as a future concept that has promise but also some clear barriers (discussed below). Automotive companies also mentioned some near-term grid service opportunities that do not require V2G capability such as responding to DR events. Both automakers suggested that they are involved in recent pilot projects that are beginning to reveal more about the potential for VGI values to be established for certain use cases in example early markets.
- The EVSE manufacturers interviewed mentioned a wide range of potential VGI value streams, and the potential to combine multiple value streams for enhanced benefits. These include taking advantage of TOU rates in California for bill savings, DR programs at workplaces for grid services, fleet VGI opportunities including with electric school buses, and residential V2G. A few of them mentioned the changing shape of the California duck curve as an opportunity for VGI to help with alleviating the evening ramp as well as valley-filling at other times of low demand.
- The companies involved in EVSE networking and grid services (e.g. aggregation of EV charging load for DR) also mentioned a range of potential VGI value streams. These include behind the meter DR and load shifting and load augmentation during times of excess grid power to help with “duck curve” issues in California, the potential for V2G as well as V1G concepts, transmission and distribution system upgrade deferral value, storage for local solar photovoltaics, and the potential for greenhouse gas emission reduction through greater acceptance of renewable sources of electricity.

Overall the various groups interviewed mentioned many of the same concepts but with a somewhat different emphasis as discussed above. They also identified a somewhat different set of current and prospective barriers to near and longer term VGI concepts as discussed in the section below.

More specifically, the electric utilities seemed most focused on clarifying VGI value and on taking advantage of cost-effective electricity rates and utility programs for V1G type concepts that already exist or are imminent, allowing the integration and management of EV load within the potential for a broader DER ecosystem. For the electric utilities, more advanced concepts like V2G continue to be of interest and should be evaluated for their potential net benefits, as the technology continues to mature. Utilities also care about and are trying to resolve some significant technical hurdles (e.g. Rule 21 for interconnection) for V2G, as well as to demonstrate the more local effects on the utilities' distribution systems. Auto companies did express interest in V2G, especially opportunities to learn from pilots which will grow their business in the longer-term. Meanwhile the EVSE manufacturers and companies working on EVSE networking expressed a fairly expansive view of VGI potential, including extensive load shifting and V2G as well as V1G types of use cases. They also stressed new policy mechanisms for VGI value capture such as the evolving California Low Carbon Fuel Standard credit program. All groups seemed to support the idea that larger project efforts and studies are needed to demonstrate VGI value potential at scale and for specific settings and use cases, as a next step in validating emerging business models for the more advanced types of VGI concepts.

Barriers to Realizing the Value of VGI

Gridworks also searched the literature and interviewed expert stakeholders to better understand the barriers to realizing the VGI value proposition. Various types of barriers were explored including technical issues, economic value proposition and policy uncertainty, communications standards and protocols, and issues with enrolling and retaining EV drivers to participate, among others.

An important finding drawn from the literature stems from a Los Angeles Air Force Base VGI study that identifies some existing barriers to V2G implementation at the ISO or wholesale level, based on a real-world study. First, for PEV fleets, the physical characteristics for (transmission and/or distribution) grid support change throughout the day, creating an immediate initial challenge compared to stationary resources. At the next level of detail, state-of-charge estimation for the aggregated vehicle battery resource is cumbersome for the ISOs to obtain in detail. Next, there are significant costs associated with participating in ISO markets, for annual participation fees, meter fees, and grid coordination/scheduling services. Related, there is a need to allow for expanded opportunities for third-party aggregators to provide CAISO services and not just LSEs as they cannot effectively charge for grid scheduling services.

The participants in the survey identified several key barriers remain for VGI implementation, including technical, economic, and regulatory/institutional types of barriers. The types and specific barriers mentioned by each key group of interviewees is summarized below.

First, the electric utility groups agreed that in order to spur VGI adoption and the success of what VGI has to offer, what is now needed is an industry-wide, collaborative focus on defining both VGI use cases and the net value (benefits and costs) for each use case. The current lack of such focus is the most prominent barrier to VGI deployment. Additional barriers highlighted by the utilities include: uncertainty and challenges with large-scale operations for commercial deployment and customer participation, current lack of cost-competitive networking solutions, and the lack of coordinated approach to collecting and synthesizing data and learnings. Electric utilities also pointed to the challenge of navigating a complex and sprawling regulatory environment, spearheaded simultaneously by multiple agencies. LastAlso, as lessons learned from implementing programs, electric utilities pointed to a need for stronger education strategies and improved enrollment processes for drivers. One of the broadest interview topic discussed was the implementation of VGI-related standards. On this topic, electric utilities stressed that the market should adopt current mature, utilized, and cybersecurity standards where appropriate. At the same time, utilities recognized that new standards may be needed as the VGI industry develops. Electric utilities believe that larger scale VGI demonstrations would be helpful both to assess the suitability of communication standards as well as to verify VGI net benefits.

The automotive companies tended to focus on issues related to VGI value stream definition, consumer awareness and enrollment, and utility interfaces as key barriers. For utility procedures as a barrier, the issues raised were related to dealing with the local utility for accessing released customer data, enrolling customers in DR programs, and dealing with an interconnection procedure for V2G systems. One manufacturer mentioned the situation with various communication standards being considered, and some confusion among the industry about how best to employ them, as a current barrier. Also, mentioned as barriers for V2G were the issues of the lack of UL listing ability for EV onboard inverters, interconnection processes for V2G systems with onboard inverters, and the potential voiding of battery warranty for V2G.

The EVSE manufacturers that were interviewed tended to focus on access to markets and driver information (especially for workplaces), communication standards, and consumer awareness/education as key barriers for VGI. More specific issues mentioned included:

- difficulty with conflicts between enrollment in multiple DR type programs, that is currently not allowed but frequently not a conflict for VGI based services;
- the need to gain better access to wholesale markets;
- relatively low levels of established values for VGI so far;
- developing software platforms for efficiently enrolling and aggregating customers for larger grid services program participation; and
- the desirability of standardizing on OCPP and OpenADR for the “cloud”-EVSE communication link. One EVSE manufacturer also commented that the industry rate of technology advance is outrunning the pace of regulatory procedure development, creating a market disconnect barrier.

Other EVSE providers add emphasis to the need to focus on barriers customers may face. Just as it is mentioned that the physical characteristics for grid support change throughout the day for PEV fleets, for EV drivers a significant percentage of their EV charging needs may be inelastic and dictated by schedules outside of their control, and as a result the value of VGI may be limited if there is no flexibility that can be realized. For example a significant percentage of EV drivers may rely on DC Fast Charging (DCFC) as their sole method of charging their vehicle in the absence of accessible workplace or home charging. The typical use case for a DCFC is to charge as quickly as possible and free up the asset for other EV drivers, and providing Demand Response (DR) or V2G services would not be practical, while general rate signals could be the extent to which VGI effects could be achieved by promoting certain times to charge, subject to congestion of charging infrastructure which could counter or even outweigh such VGI rate signals.

The grid services company experts mentioned some similar themes to the EVSE manufacturer representatives, such as issues of aggregating customers for market participation and how to take advantage of opportunities with both retail and potentially wholesale markets and price structures. The grid service companies also mentioned a number of additional more technical issues and barriers such as the ability of VGI to provide local distribution level voltage support/response but without a mechanism for compensation, the inability to export power beyond the level of local loads (barring an export agreement with the utility and full interconnection), and the need to identify which meter the EVSE is connected to for Sublap zone identification purposes. Two of the three companies mentioned communication standards as a barrier, with one favoring a convergence on ISO 15118 as a leading and internationally-focused solution. One company also stressed the costs of CAISO metering and associated grid services scheduling as barriers for participation in the wholesale market in California. Finally, one technology provider identified a lack of standards for communicating data and of a low-cost submetering solution as challenges. One has to collect the – accurate - data in order to apply financial incentives, including EV-only tariffs rather than whole-house, and one has to share the data between the parties, each of whom realizes a piece of the value stack.

The above discussion highlights that there is still a range of identified barriers to VGI implementation including both technical and regulatory obstacles. It also shows that significant progress has been made, revealing a more detailed set of challenges as some of the more basic hurdles are being overcome. With regard to varying views among the groups, in general the utility groups emphasized the challenges with articulating VGI value then prioritizing VGI use-cases, which is important for market maturity and customer adoption. They also noted some regulatory barriers such as navigating a multi-pronged regulatory landscape and the lack of clear framework for coordination among state agencies. Next, the automobile companies tended to cite as barriers the uncertain value streams from VGI, customer awareness and recruitment issues, and some technical issues such as onboard inverter certification for VGI. They seem to be experimenting with different communication standards and are not seeing that as a major barrier.

Meanwhile, EVSE manufacturers stressed access to markets in ways that are amenable to VGI services, and mechanisms for conferring information and opportunities to EV drivers as key barriers. They also highlighted regulatory issues such as prohibitions that for example prevent EV drivers from participating in VGI-based DR programs if they already are in a household DR program. Finally, the grid services companies identified different barriers relative to realization of onsite benefits, versus access to distribution-level and wholesale-level values, each with its own set of challenges. They also identified the costs of market participation particularly for smaller fleets trying to access value at the wholesale level.

VGI Use Case Evaluation Method

The method offered here provides a path for answering the following questions:

- *What VGI use cases can provide value now, and how can that value be captured*
- *What policies need to be changed or adopted to allow additional use cases to be deployed in the future?*
- *How does the value of VGI use cases compare to other storage or DER?*[24]

While these questions are simple on the surface, a morass of complexity underlies them. Untangling the relationship between VGI opportunities, customer and grid services, and public policy, both existing and potential, presents a formidable challenge. Thus, *a key takeaway from the Gridworks VGI Initiative is the need for a transparent, systematic method for VGI use case evaluation.* The following section offers such a method, informed by active input from participating experts in the Gridworks VGI Initiative. The section provides:

- principles and priorities for a VGI Use Case Evaluation Method,
- an outline of the steps that need to be made in sequence,
- data needs, and
- major judgement calls that impact implementation.

This method is designed for a participatory decision-making process which includes diverse stakeholders.

Principles and Priorities

The following principles and priorities were developed to guide this method of use case evaluation. They were developed by Gridworks based on input by participants in the VGI Initiative.[25] The method should be:

- Inclusive without prejudice
- Able to leverage available information, identify and narrow any information gaps, and adapt to new information
- Reasonably efficient to implement, balancing progress, consensus building, time and accuracy
- Technology and business model neutral
- Transparent and clear

[24] R.18-12-007. CPUC
[25] These principles and priorities may not represent the priorities or positions of all participants.

- Allows quantifiable analysis and assessment of benefits and costs
- Capable of recognizing the needs and interests of a broad constituency

These principles are not presented in order of their importance or weighted.

PG&E VGI Valuation Method

Guided by these principles and priorities, below is a suggested a six-step VGI valuation method by PG&E.[26] The method is presented sequentially in this section. The steps are:

Step 1: Define A VGI Framework
Step 2: Identify Hypothetical Use-Cases
Step 3: Screen Out Impractical Use-Cases
Step 4: Assess Each Use Case's Potential Benefits and Costs
Step 5: Prioritize Use-Cases
Step 6: Infer Recommendations on Policy, Market, or Technology in Order to Realize and/or Improve the Use Cases Value

Based on input from stakeholders in the VGI Initiative Workshops, as well as its own judgement, Gridworks identifies **questions** which may need to be addressed, and the corresponding data needs for each of the six steps. Furthermore, where a **judgement call** has the potential to significantly impact the course or outcome, Gridworks discusses potential choices and tradeoffs. Those notes by Gridworks are highlighted in distinct call-out boxes throughout PG&E's VGI Valuation Methodology.

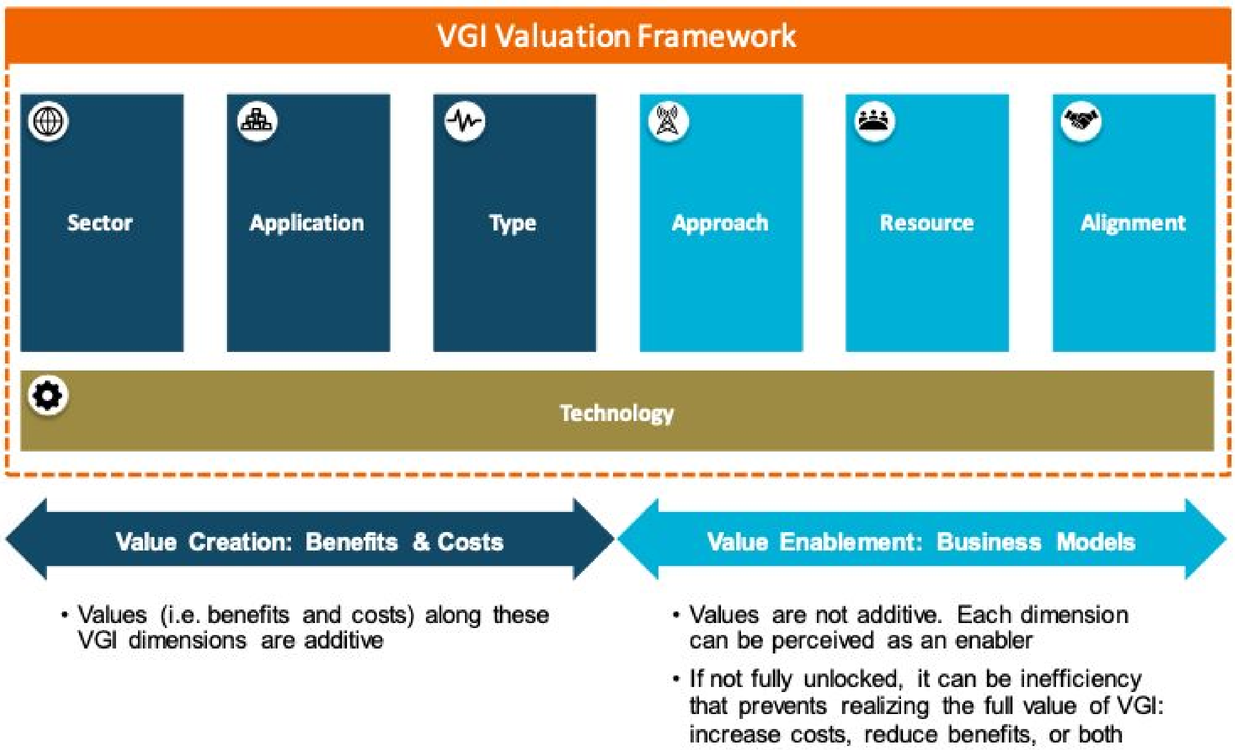
Step 1: Define An VGI Framework
This first step identifies seven key *dimensions* along which VGI use-cases can be designed, and their value subsequently quantified. The dimensions are illustrated in Fig 1 and summarized below, and a detailed description is included in Appendix B.[27]

- **Sector**:
    - Pinpoints where the vehicle is used and charged
    - Could be broadly grouped into *residential*, *commercial*, or *rideshare* categories or subsets thereof (e.g., commercial fleets or commercial public)
    - Determines the loadshapes – both in "reference" and "optimized" charging forms – that are to be associated with the VGI use-case
- **Application:**
    - Refers to the service(s) VGI is used to provide

[26] Karim Farhat. *PG&E VGI Valuation Methodology and Framework*. Presentation made at Gridworks VGI Initiative. Except for the call-out boxes labelled "Gridworks notes", the content in the section titled "PG&E VGI Valuation Method" is provided by PG&E (with limited edits).
[27] PG&E's VGI Valuation Framework, as published in "*A Comprehensive Guide to Electric Vehicle Managed Charging*" SEPA, May 2019. Page 20.

- Could broadly grouped into *customer-centric*, *grid-centric*, and *wholesale-market-centric* services, including several of the potential applications listed in Figure 2
- The prospect of "stacking" these services, and their values, is important and relevant not only to VGI but also to other DERs such as battery energy storage.

Figure 5



- **Type**:
  - Determines the power-flow involved between the grid and the vehicle
  - Could be uni-directional (*V1G*) or bi-directional (*V2G*)
- **Approach:**
  - Refers to the control mechanism through which the vehicle's charge or discharge is managed
  - Could be either *direct (i.e. active)* or *indirect (i.e. passive)*; utility billing rates are a good example of passive control mechanism, whereas demand response is a good example of active control mechanism
  - *Gridworks note: This dimension may also capture the potential need for and role of aggregation*
- **Resource:**
  - Assesses whether the vehicle and its charger are controlled and/or operated by the same actor, or by different actors
  - Defines whether the EVSE-EV actors are *unified* or *fragmented*
- **Alignment:**

    - Alignment and Resource are tightly linked
    - When the EVSE and EV actors are *unified*, they are *aligned* by default
    - In the case that the EVSE and EV actors are *fragmented*, they may be either *aligned* or *misaligned*
    - Among other factors, incentive design may be an important consideration to achieve alignment and guarantee the delivery of the VGI service
- **Technology:**
    - Identifies the hardware and software needed to realize the opportunity
    - Could be a wide-range of variants (e.g., vehicle type, charge type, communication requirements)
    - Technology solution sets are diverse and span across the other six VGI dimensions

PG&E's framework treats Sector, Application, and Type as "value creation" dimensions, since they determine how VGI value (both benefits and costs) is created and where it comes from. Value along these dimensions is additive: residential charging can be added to commercial charging; wholesale ancillary services can be added to capacity services, and managed charging can be added to managed discharging, resulting in additional benefits and/or costs.

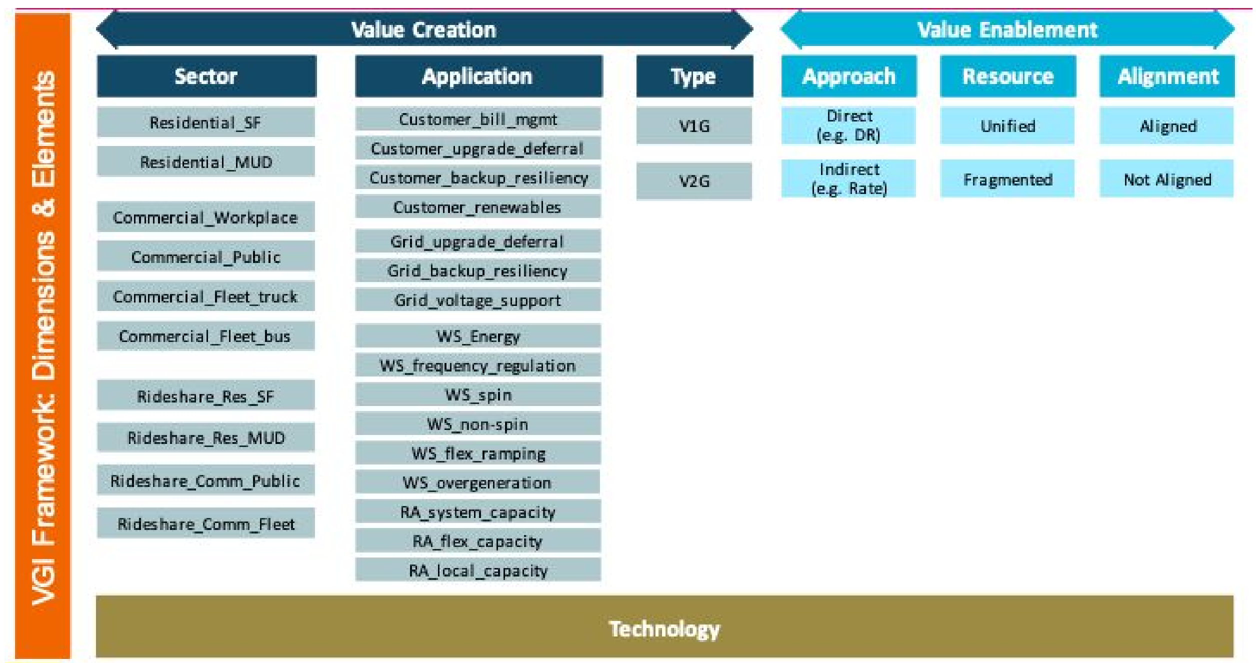
PG&E's framework also treats Approach, Resource, and Alignment as "value enablement" dimensions, since they determine how VGI value (both benefits and costs) can be unlocked and effectively captured. Value-enablement dimensions compliment value-creation dimensions to accurately characterize benefits and costs. For example, no matter how significant the potential net-benefits may be from leveraging managed charging of EV fleets for distribution-capacity deferral, that value may never been realized in real life if the approach is inappropriate, the resource is fragmented, and/or the actors are misaligned.

Gridworks Notes
Some questions that may need to be addressed in this step include:

A. *Do the seven dimensions provided herein reflect key contours of today's VGI landscape?*
B. *Is further refinement of "Approach," to include what regulatory and / or market construct (rates, tariffs, programs, wholesale market pathways, etc.) are needed, necessary to assess the value of VGI use cases?*

Step 2: Identify Hypothetical Use Cases

Figure 6



Together, the aforementioned seven *dimensions* constitute the main pillars of a VGI framework by which use-cases are scoped and defined. Under each dimension, several options can be identified; we refer to those options as *elements*. For example, as shown in Fig 2, *Customer Bill Management* and *Wholesale Energy* are elements of the dimension *Applications*. Some of the key dimensions, such as Sector or Application, could have many potential elements.

This method defines a use-case as a unique combination of elements under the seven dimensions identified in the framework. To illustrate, below we present an example VGI use-case by choosing a Sector, an Application, and a Type, then selecting an Approach, identifying the nature of the Resource and the corresponding degree of Alignment, and highlighting the relevant Technology:

Example: Amazon Delivery Fleet
Sector: Commercial Fleet
Application: Customer Bill Management

Type: V1G
Approach: Direct (e.g., Demand Response)
Resource: Unified
Alignment: Aligned
Technology: Electric Vans; OpenADR Communication Standard; DCFC Charging

VGI use-cases could be simple or advanced. A simple use-case consists of only one choice for each dimensional element, as in the example provided above. An advanced use-case may consist of multiple choices for each dimensional element, as would be the case if the commercial fleet in the above example provided energy and capacity services in the wholesale market.

In theory, hundreds of combinations of elements in the framework could be made, resulting in hundreds of hypothetical VGI use cases.

Gridworks Notes
Questions that may need to be addressed in this step include:

A. *Which of the outlined elements in Fig 5 may be difficult to clearly define and why?*
B. *Are the most likely sectors, applications, and approaches of VGI properly accounted for in the outlined elements under each dimension of Figure 2? Should the list of identified elements under each dimension require additions or subtractions?*
C. *Which elements should be explicitly called out? What guidelines or standards should be created to add transparency and efficiency to implementation?*
D. *Is there a point at which the list gets "locked down" to allow for efficiency in implementing subsequent steps?*
E. *How rigid or flexible should the implementation of this method be in revisiting this step?*
F. *Considering simple use cases that only provide a single application relative to other simplice use cases may be more practical than comparing advanced use cases. How should this relative simplicity be take into account?*

Judgement Call:
First, as explained by PG&E, some of the key dimensions such as Sector or Application could encompass numerous elements, resulting in potentially hundreds of use-case permutations; each managed charging situation is arguably unique. The degree to which potential permutations are factored in the VGI evaluation methodology impacts the inclusivity and efficiency of the methodology: too few may exclude opportunities, too many may complicate and

weigh down the implementation. ***Stakeholders need to think carefully about: striking the right balance between inclusivity and efficiency when carving out distinct elements under each dimension***

Second, two paths forward emerge at this step. Down the first path (a "broad path") an approximately comprehensive list of VGI use-cases is assembled and prepared for screening, valuation and prioritizing in subsequent steps. A second path ("narrow path") aims to narrow the list of VGI use-cases based on the interest and buy-in of stakeholders. Down this path, the list of VGI use-cases that receive full evaluation gets shortened to those agreed-upon by stakeholders. There may be a need to consider the merits to each path, especially when the principle of efficiency in implementation gets considered. If one concludes the championed use-cases really are the most viable ones, the narrow path may save time and effort. The subsequent steps are required for either path, but the time, data and effort required to implement them may differ depending on the decision made by stakeholders. ***Stakeholders need to think carefully about whether the broad or narrow path is better to meet the industry's needs and aspirations on VGI.***

Step 3: Screen Out Impractical Use-Cases
Having the full range of hypothetical use-cases to evaluate, the next important consideration is what screens can be applied to filter out impractical use-cases. Screens may emerge from physical technical limits, market rules, policy, or customer preferences, among other considerations. Screens may also be shaped by the intended timeframe of the evaluation. For example, potential screens might include:

- Technical feasibility: Can a vehicle provide capacity or resource adequacy service in the wholesale market by relying on passive control mechanisms such as time of use rates?
- Customer behavior: Will a driver at a public DC fast charger be willing to discharge their battery at that charger to provide grid services?
- Data availability: Does data exist today to quantify the value of using large trucks as mobile backup generation units?

These illustrative screens are by no means comprehensive. Part of the evaluation of VGI use cases may involve developing and defining criteria to guide the process of screening for impracticalities. Some screens may be subjective, in which case stakeholders should aim to agree on standards and guidelines to design, interpret, and implement them..

Gridworks Notes
Questions which may need to be answered during this step include:

A. *What legal, policy, market or technical limits exist to inform the screening of theoretical use-cases due to practicality?*
B. *Which screens are objective and non-controversial?*
C. *Which screens are subjective? What standards or guidelines could be used to design, interpret, and/or implement such screens?*

D. *Give the above, which screens should ultimately be employed in this step and why?*
E. *Could a use-case be composed of dimensional elements that are inherently incompatible?*
F. *Could any of the screens be changed through policy amendments? If so, identify them for further consideration in step 6.*

Judgement Call
Step 3 may be in tension with the principle of inclusivity and therefore certain judgement calls emerge. First, there are many potential market, legal, policy, or technical limits which may be leveraged as screens. ***Stakeholders need to think carefully about: (1) the degree of confidence they have in their proposed screens; through research and stakeholder engagement, their ability to identify all potential market, legal, policy, or technical limits that should be used to screen use cases.*** *Being comprehensive at this stage will avoid losing time in later steps. Second, there may be use-cases which get filtered out through the screening process but show promise for other reasons.* ***Stakeholders need to think carefully about use-cases which fail the screens but may nevertheless warrant further consideration. Do such use cases exist? and why? How will such use cases be handled in Step 4 and 6?***

Step 4: Quantify Each Use Case's Potential Benefits and Costs
Having identified potential use cases and screened them for impracticalities, this method turns next to quantifying the potential benefits and costs of use cases.

In this method, a use case's benefit can be modelled and optimized by potentially considering five broad sets of inputs: (1) some form of a "reference", (2) plug-in schedule that shows when the EV is connected and available to interact with the grid, (3) an economic signal (e.g. price of service) to maximize or minimize charge/discharge, (4) battery characteristics or constraints (e.g. battery capacity in kWh), and (5) EV-EVSE characteristics or constraints (e.g. energy demand for mobility needs, level of charging, etc.). The output from this exercise is an optimal EV charging profile. Comparing the optimized output to the reference allows deducing the quantitative benefits of the investigated use-case. In addition, it is important to factor in the various categories of costs that are needed for the use-case to be fulfilled. This may include hardware and/or software, fixed and/or variable, as well as admin expenses. Accounting for both benefits and costs would then determine the use-case's value in terms of net-benefits.

Gridworks Notes
Questions to be addressed in this step:
A. Have all potential benefits of a use case been identified and assessed?
B. What publicly available sources of benefit and cost values, including existing tools and/or datasets, can be leveraged for this step?[28]

[28] For example, the CPUC's Avoided Cost Calculator can be accessed at https://www.cpuc.ca.gov/general.aspx?id=5267.

C. Are the publicly available sources of benefit and cost values, including existing tools and/or datasets, current and sufficient? Do they need to be updated or supplemented?
D. If available data is not sufficient, what other resources or initiatives may be needed to obtain missing data?
E. Do the estimated benefits and costs provide an adequate representation of the relative value of each evaluated use case? If not, why not?

Judgement Call
The exact mechanics of conducting such quantitative analysis may be subject to subsequent more detailed discussions, or tailored approaches, by the industry stakeholders. Still, agreeing to a rigorous, methodical, and quantitative approach is important to ensure transparent and consistent accounting of value for each VGI use-case, as well as transparent and consistent comparison of value across the wide set of VGI use-cases. **Stakeholders need to think carefully about: (1) The goals for the quantitative analysis, being it to inform policy decisions, decide on state-level investments, prioritize programs, or otherwise. (2) The level of granularity and detail needed for the analysis to serve its goal.**

Step 5: Prioritize Use Cases
The results of Step 4 feed into Step 5 showing the relative potential benefits and costs of each use case. These results, shown in rank order from the most to least valuable, provide an initial indication of which use cases to prioritize. Here, more than one value metric (focusing on net-benefits) may be considered to rank and prioritize the use-cases.

Gridworks Notes
Questions that may need to be addressed in Step 5 include:

A. *What value metrics may be considered to rank or prioritize use-cases?*
B. *Are there factors impacting the timing and practicality of implementing a use case that should be considered? Does the willingness of customers to participate deserve special consideration, given their centrality to VGI?*
C. *Should there be a "cut off" value by which higher value use-cases move forward get prioritized? If so, what should that cut off be?*
D. *Are there any use cases that should be prioritized despite being relatively lower value? If so, why?*
E. *Are there policy or market changes that should be considered in Step 6 to improve the value of lower-value use cases?*

Step 6: Infer Recommendations on Policy, Market, or Technology in Order to Realize and/or Improve the Use Cases Value
This final step draws on all previous steps to infer recommendations by which policy, market, or technological changes could enable other use cases to be practically enabled or improve their

value. The results of this step are recommendations to policy makers, market participants, or technology and solution providers that could result in more, higher value VGI use cases.

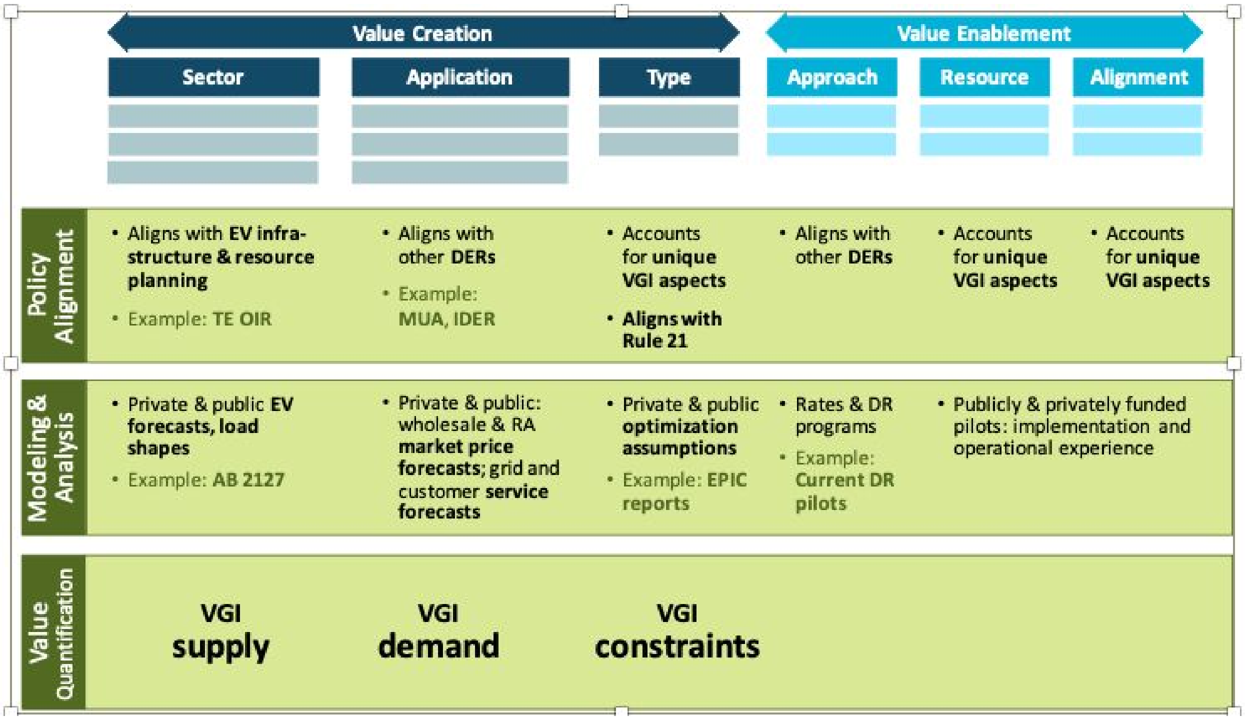
Gridworks Notes

Questions to be addressed in Step 6 include:

- *What potential policy, market, or technology screens in Step 3 warrant a recommendation to policy makers, market participants, or technology providers in Step 6?*
- *What policy or market changes which impact the value of a use case warrant a recommendation?*

Combined, these six steps break the inquiry on VGI evaluation into manageable pieces, addressed in a sequence that allows for transparent, efficient, and inclusive consideration of use cases. More broadly, as highlighted in Fig 3, the proposed VGI Valuation Methodology and Framework helps achieve three key objectives: (1) aligning VGI policy and regulations with those impacting the broader transportation electrification goal and other DERs; (2) identifying and gathering the necessary information and data – including leveraging existing information and data – needed for VGI valuation; (3) developing a robust analytical tool to quantify VGI benefits and costs.

Figure 7



Next Steps

As organized in this Framing Document, there is much to gain from a concerted effort to advance VGI. Critical and hard-fought progress was made by stakeholders in the 2017 Working Group and through Gridworks' VGI Initiative, but work remains to be done.

In this Framing Document we make a first step by reviewing the 2017 Working Group materials, sharing the results of a literature review and expert survey on the value and barriers of VGI, and providing a platform to discuss how PG&E's Valuation Method addresses the different pieces of the puzzle.

Gridworks concludes the road forward depends heavily on collaboration between key stakeholders. Only through deliberate collection and organization of the diverse stakeholders within the VGI community can such a complex challenge be met.

Appendix A

Gridworks VGI-Initiative Summary

The Gridworks led Vehicle Grid Integration (VGI) -Initiative held four workshops between April and June (2019). This initiative convened stakeholders from a range of interests including Original Equipment Manufacturers (OEM's), Investor owned utilities (IOUs), Community Choice Aggregators (CCAs), Electric Vehicle Supply Equipment (EVSE) providers, DER aggregators and utility regulators. The objectives of the working group were to: engage stakeholders, scope the VGI initiative and socialize approach to VGI Use Case evaluation. The information below provides a high-level summary of the work completed during the four workshops including the groups revised VGI definition, the principles and priorities for use case evaluation, and the identified data gaps for completing the VGI use case evaluation.

VGI Definition:

Old definition:
Vehicle - Grid Integration (VGI) is a key concept that can flip the integration of 5 million cars onto California's grid from a problem to an opportunity. California's VGI Working Group describes VGI as "the many ways in which a vehicle can provide benefits or services to the grid, to society, the EV driver, or parking lot site host by optimizing plug-in electric vehicle (PEV) interaction with the electrical grid."[29] VGI includes:

- active management of electricity (e.g., bi-directional management, such as vehicle-to-grid power flow [also known as V2G];
- unidirectional management such as managed charging [also known as V1G]) and/or active management of charging levels by ramping up or down charging; and
- passive solutions such as customer response to existing rates, design of improved utility rates (e.g. time-of-use (TOU) charges, demand charges and customer fees), design of the grid to accommodate EVs while reducing grid impacts to the degree possible, and education or incentives to encourage charging technology or charging level (e.g. rebates for lower level charging, modifying current allowance policy).

Feedback on old definition:

- 2017 definition is too long, with too many specifics
- Maintain a "mobility first" emphasis to support accelerated electrification of transportation; don't put the cart (grid services) before the horse (mobility)
- Should complements/fits California's larger DER definition and framework
- Needs to answer the main question: "Who is it for? Who benefits?"

[29] "VGI Glossary of Terms" California Public Utilities Commission. http://www.cpuc.ca.gov/vgi/

- Should serve marketing purposes
- Emphasis on EVs as an integral part of the grid, rather than the grid as something that must accommodate EVs
- Careful not to confuse V1G, V2G, charge and discharge
- Don't get too hung up on the definition...

New VGI definition:
For purposes of this Framing Document, we rely on California's SB676, which defines VGI as follows:

> *"Electric vehicle grid integration" means any method of altering the time, charging level, or location at which grid-connected electric vehicles charge or discharge, in a manner that optimizes plug-in electric vehicle interaction with the electrical grid and provides net benefits to ratepayers by doing any of the following: (A) Increasing electrical grid asset utilization; (B) Avoiding otherwise necessary distribution infrastructure upgrades; (C) Integrating renewable energy resources; (D) Reducing the cost of electricity supply; (E) Offering reliability services consistent with Section 380 or the Independent System Operator tariff"*[30]

VGI includes both managed charging and demand-response use cases (V1G), as well as use cases in which vehicle batteries discharge stored power back onto the grid (V2G).

Principles and Priorities for Use Case Evaluation:
During the VGI workshop stakeholders were asked to identify and assess opportunities in which VGI can create value from multiple market participants' perspectives. Gridworks originally proposed a methodology for use case evaluation focusing on the use-case/benefit/policy connections. Stakeholders recognized the importance of a defined framework for use case evaluation but struggled with the originally proposed framework. Subsequently, PG&E proposed an alternative VGI Use-Case Valuation Methodology and Framework, which was shared and discussed in detail among the workshop participants. In parallel, participants focused their attention to the principles and priorities that a use case evaluation framework should include.

The participants offered the following principles for a VGI Use Case Evaluation Framework:
1. Inclusive without prejudice
2. Able to:
   a. leverage available information
   b. identify and narrow any information gaps
   c. adapt to new information
3. Reasonably efficient to implement, balancing progress, consensus building, time and accuracy
4. Technology and business model neutral
5. Transparent, simple and clear

[30] SB676 as of August 12 (http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200SB676)

6. Allows quantifiable analysis and assessment of benefits and costs
7. Capable of recognizing the needs and interests of a broad constituency

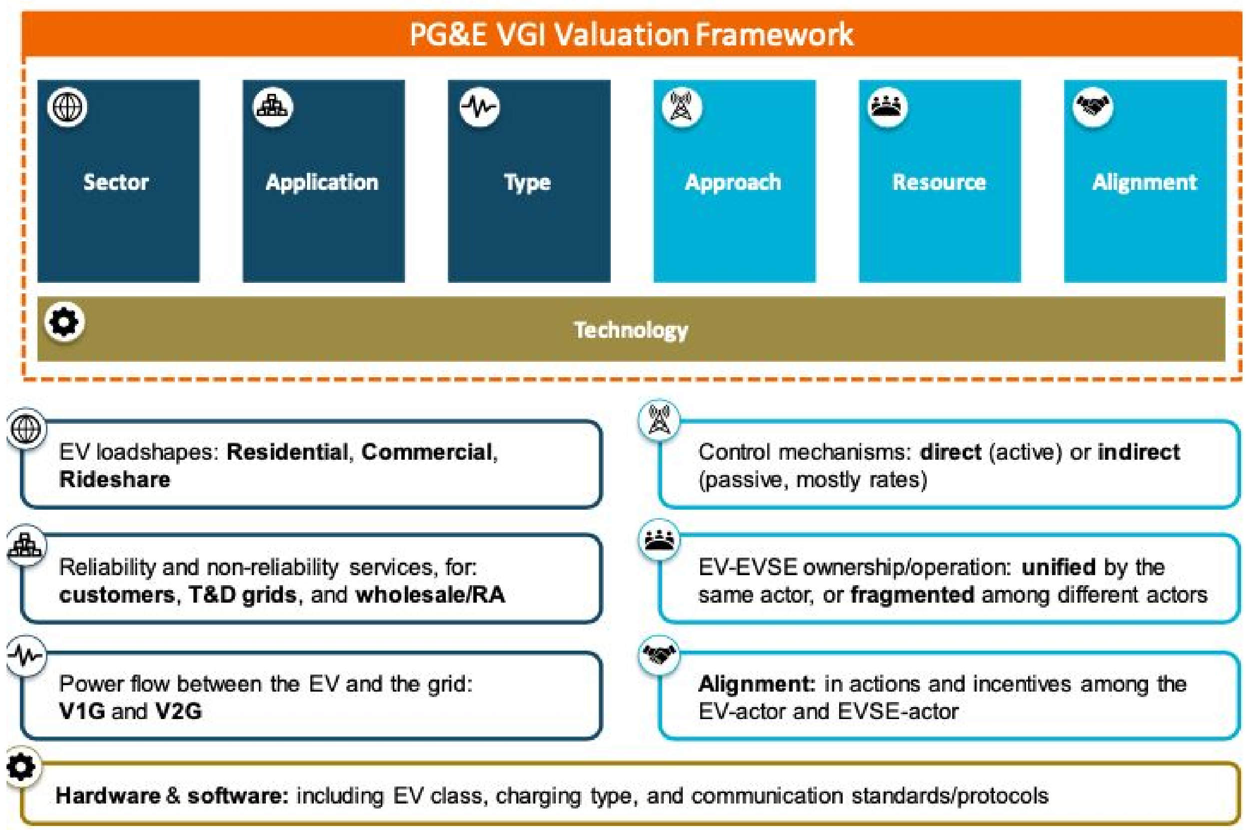
Additionally, stakeholders believed a use-case evaluation framework should:

- be oriented to first identify the grid needs and EV loads, and second assess whether VGI can meet them.
- Identify and address the significant data required to execute a VGI evaluation framework. For example, the type, organization and source of EV charging references. A targeted, focused push to identify what we have, what can be shared, and how, may be a valuable next step.

Appendix B

PG&E VGI Valuation Framework

Building on the progress achieved during the California Public Utilities Commission VGI Working Group, PG&E took the initiative to develop a VGI framework that can help advance the work on VGI valuation. PG&E's VGI Valuation Framework identifies seven key dimensions along which VGI use-cases can be designed, and their value subsequently quantified. While this framework may still evolve as the industry progresses, it can significantly help different stakeholders think and communicate with clarity and accuracy about VGI.



The seven dimensions are described in more detail below:

1. **Sector:** It is important to define the sector where the vehicle is used and charged, because that most often determines the corresponding EV load shape and therefore the load management opportunity. Broadly speaking, the three main sectors with unique load shapes are residential (e.g. single-family or multi-unit dwellings), commercial (e.g. workplace, fleet, or public) and rideshare. For example, a residential light-duty vehicle charging profile looks

very different from that of a commercial-fleet medium- or heavy-duty vehicle. Different load profiles result in different load management actions and yield different VGI values, depending on the needs.

2. **Application**: Refers to the service(s) the EV is used to fulfill. PG&E breaks down applications into reliability and non-reliability services, which are further characterized at the customer-level (e.g., customer bill reduction), transmission and distribution grid level (e.g., capacity investment deferral), and the broader wholesale market level (e.g., ancillary services, capacity, renewable integration, etc.). An EV may fulfill, and therefore may get compensated for, one or more of these services. The prospect of “stacking” these services, and their values, is important and relevant not only to VGI but also to other DERs such as battery energy storage.

3. **Type:** This defines the power flow between the EV and the grid. A uni-directional flow (V1G) results in charging modulation (increase or decrease load) only, whereas a bi-directional flow (V2G) also allows discharging the EV back to the facility or all the way back to the grid. These different types have different associated capability sets and therefore result in different values.

PG&E’s framework treats Sector, Application, and Type as “value creation” dimensions, since they determine how VGI value (both benefits and costs) is created and where it comes from. Value along these dimensions is additive: residential charging can be added to commercial charging; wholesale ancillary services can be added to capacity services, and managed charging can be added to managed discharging, resulting in additional benefits and/or costs from VGI.

4. **Approach:** Managed charging can be defined as both active (e.g. through demand response) and passive (e.g. through time-of-use rates). The control mechanisms by which load management is enabled have different associated costs and benefits. For example, DR events may result in limited load shifting during specific time periods on specific dates, whereas TOU rates may result in consistent load shifting on daily basis throughout the year. DR participation may result in high benefits per event while necessitating nontrivial investment in technological upgrades. On the other hand, TOU rates may result in consistent savings over time while imposing modest administrative costs to setup and run the program.

5. **Resource:** Defines whether the EVSE-EV actors are unified (e.g., a fleet operator that owns the vehicle and the charger) or fragmented (e.g., a workplace charger that doesn’t control how EV-driving staff use the asset). When EVSE-EV actors are unified, it is easier to fulfil the VGI application and capture its value. When EVSE-EV actors are fragmented, further effort may be needed to ensure their alignment, which is the focus of the next VGI dimension.

6. **Alignment:** Alignment and Resource are tightly linked. When the EVSE and EV actors are unified, they are aligned by default. In the case that the EVSE and EV actors are fragmented, they may be either aligned or misaligned. Among other factors, incentive design is an important consideration to achieve alignment and guarantee the delivery of the VGI service. Absent this alignment, managed charging/discharging may never get to fulfill its purpose, and the value of VGI would be eroded.

PG&E's framework treats Approach, Resource, and Alignment as "value enablement" dimensions, since they determine how VGI value (both benefits and costs) can be unlocked and effectively captured. Value-enablement dimensions compliment value-creation dimensions to accurately characterize benefits and costs. For example, no matter how significant the potential net-benefits may be from leveraging managed charging of EV fleets for distribution-capacity deferral, that value may never been realized in real life if the approach is inappropriate, the resource is fragmented, and/or the actors are misaligned. Effectively, the value-enablement dimensions help inform the design of successful business models for the VGI use-cases, and they help identify any technological, policy, or market gaps that need to be resolved for that purpose.

7. **Technology:** includes the hardware and software to bring about the necessary capabilities to fulfill a VGI offering. Technology solution sets are diverse and span across the other six VGI dimensions. Examples of technology considerations could include the type of EV (e.g., light-duty vehicle versus heavy-duty vehicle, or plug-in hybrid vehicle versus battery electric vehicle; a battery electric vehicle typically has a larger battery capacity than a plug-in hybrid electric and therefore more opportunity for load shifting), the charger type (e.g., a networked L2 charger may be more expensive but allow higher charge/discharge rate than a networked L1 charger), and the corresponding communications protocols to pass information and commands between the vehicle and ultimately the grid.

PG&E sees the VGI landscape as a decision tree that keeps branching out, with each branch ultimately characterizing a unique use-case. A VGI use-case is defined by choosing a Sector, an Application, and a Type, then selecting a direct or indirect Approach, a unified or fragmented Resource, and the corresponding degree of Alignment.

The following are two examples of a VGI use-case:

• Residential (Sector) EV load decrease (Type) in the afternoon to avoid peak pricing and minimize monthly energy bill (Application) by setting charger timer based on TOU rate schedule (Approach), where both the charger and EV are owned by the meter customer (Resource and Alignment).

• Workplace (Sector) EV load increase (Type) to soak up excess renewable energy during the day (Application) via DR (Approach), where the EVSE and EV are operated by different actors (Resource and Alignment).

Ultimately, this framework yields hundreds of possible VGI use-cases. While all use-cases may be worthy of consideration, some will likely be more valuable and/or market-ready than others. PG&E's approach helps clarify the granularity of the VGI use-cases while inclusively accounting for all of them, and then gathering the necessary information and data to quantify benefits and costs and to design successful programs. While some industry stakeholders can – and tend to – focus their business offerings on a limited set of use-cases, the utility needs to be able to assess, compare, and plan across the full range of feasible and implementable use-cases since they all eventually impact the grid.

Overall, the VGI Valuation Framework PG&E developed helps achieve three objectives: (1) defining a comprehensive list of VGI use-cases, (2) quantifying their value, and (3) aligning VGI policy and regulations with those impacting the broader transportation electrification goal and other DERs. Simply put, the framework serves as an accounting mechanism that charters a clear path for VGI valuation.

VGI-Initiative feedback on proposed PG&E VGI Valuation Methodology and Framework: Workshop participants offered PG&E feedback on its preliminary Use Case Valuation Methodology, including the above Framework. Top-line takeaways were the following:

- Feedback from some stakeholders suggested the framework may be better reoriented to first identify the grid needs and second assess whether VGI can meet them. It has been suggested that the PG&E method reaches the same conclusion, albeit from the opposite direction, by first understanding EV load then assessing how that load can meet grid needs. Further consideration may be warranted.
- Feedback from some shareholders suggested that PG&E should consider what, if any, additional granularity would benefit the "sectors" (e.g., commercial public charging) and "applications" (e.g., demand charge vs. volumetric rate management), balancing efficiency and inclusivity. Stakeholders acknowledge the framework is already very complex, but some stakeholders struggled to think through certain use cases (e.g., commercial fleets) and interpret certain situations (e.g., aligned vs. not-aligned)
- Feedback from some shareholders suggested there are significant data needs to execute this (or likely any) VGI evaluation framework. For example, the type, organization and source of EV charging references. A targeted, focused push to identify what we have, what can be shared, and how, may be a valuable next step.
- Overall, many stakeholders expressed verbal appreciation and support for PG&E's Framework. CalETC specifically shared its formal decision to adopt and support PG&E's VGI Framework and Methodology as an adequate and effective way to address the PUC's questions on VGI value, which will be further investigated in the VGI Working Group.

Appendix C

Data/Information needed

Based on stakeholder feedback and CPUC requests to focused on identifying the data sets that may be needed to successfully assess the value of VGI. Stakeholders identified the following information needed:

- Sources of "reference charging" (baselines, but for the EV profile (only)). What are the sources and how are they derived? Are they measured at the EV or the EVSE?
- What data on pricing/curtailment will be used to establish customer price or dispatch signal(s)?
- What assumption are we making about the underlying power supply (i.e., what electricity is being used and where did it come from)? How does valuation change based on the underlying power supply?
- What is the value of low carbon fuels standard credits (now and in the future)?
- Does Vehicle Miles Travelled (VMT) impact the use case valuation? If so, how are VMT inputs established?
- How responsive are EV customers to price (customer elasticity)?
- When does plug-in/plug-out occur for different customer types (e.g., commuter vs non-commuter)?
- How much energy is needed to support mobility (accounting for different customer types)?

Some of the above information/data may be currently available but accessing/sharing it will be a challenge.

Appendix D

VGI Initiative Stakeholder Participant List:

- American Honda Motor Company
- BMW
- Cal Electric Transportation Council
- California Energy Commision
- California Energy Storage Alliance
- ChargePoint
- California Public Utilities Commission
- E3
- East Bay Clean Energy
- Electrify America
- eMotorWerks
- Energy Foundation
- EVgo
- Fiat Chrysler
- General Motors
- Greenlots
- Gridworks
- Honda
- Kitu
- Nissan USA
- Nuvve
- Olivine
- Pacific Gas & Electric
- Southern California Edison
- San Diego Gas & Electric Company
- Siemens
- Tesla
- Toyota
- Transportation Sustainability Research Center
- The Utility Reform Network

Appendix E

Vehicle-Grid Integration Expert Interview Participation

The experts interviewed for this project included the following organizations and individuals. The project team greatly thanks them for their participation.

1. Pacific Gas and Electric Company - Karim Farhat
2. San Diego Gas and Electric Company - Hannon Rasool
3. Southern California Edison Company - Dean Taylor
4. Automobile Company A
5. American Honda Motor Company - Jeremy Whaling
6. Siemens – Chris King
7. EVgo - Bill Ehrlich and Jeremy Whaling
8. eMotorWerks - David Schlosberg
9. ChargePoint - Craig Rodine and Kevin Doyle
10. Nuvve - Jackie Piero
11. Oxygen Initiative - Steve Davis
12. Olivine, Inc. - Joseph Bourg