Pacific Gas and Electric Company

EPIC Final Report

Program	***Electric Program Investment Charge (EPIC)***
Project	***EPIC 2.03b – Test Smart Inverter Enhanced Capabilities – Vehicle to Home***
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Table of Contents

List of Tables

List of Figures

Table of Acronyms

AB	Assembly Bill
AC	Alternating Current
AFV	Alternative-Fueled Vehicle
AHJ	Authority Having Jurisdiction
AMI	Advanced Metering Infrastructure
ATS	Advanced Technology Solutions (PG&E)
BEV	Battery Electric Vehicle
CAISO	California Independent System Operator
CBP	Capacity Bidding Program
CEC	California Energy Commission
CO2	Carbon Dioxide
CPUC	California Public Utilities Commission
DC	Direct Current
DER	Distributed Energy Resource
DOD	Department of Defense (United States)
DOE	Department of Energy (United States)
DOT	Department of Transportation
DR	Demand Response
EDISON	EVs in a Distributed and Integrated market using Sustainable energy and Open Networks
EPIC	Electric Program Investment Charge
EPRI	Electric Power Research Institute
EMS	Energy Management System
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
ICC	International Code Council
IEEE	Institute of Electrical and Electronics Engineering
IOU	Investor-Owned Utility
ISO	Independent System Operator
ISO/IEC	International Organization for Standardization / International Electrotechnical Commission
kW	Kilowatt
kWh	Kilowatt-hour
LAAFB	Los Angeles Air Force Base
LBNL	Lawrence Berkley National Laboratory
MW	Megawatt
MWh	Megawatt-hour
NEC	National Electrical Code
NEM	Net Energy Metering
NFPA	National Fire Protection Association
NREL	National Renewable Energy Laboratory
O&M	Operations and Maintenance
PACT	Program Administrator Cost Test
PCT	Participant Cost Test
PEV	Plug-In Electric Vehicle
PHEV	Plug-In Hybrid Electric Vehicle
PG&E	Pacific Gas & Electric
PLC	Power Line Carrier

PV	Photovoltaics
R&D	Research and Development
RIM	Ratepayer Impact Measure
RPS	Renewable Portfolio Standard
SAE	Society of Automotive Engineers
SB	Senate Bill
SOC	State of Charge
SS	Stationary Storage
SSP	Supply Side Pilot
TD&D	Technology Demonstration and Deployment
TOU	Time of Use
TRC	Total Resource Cost test
UCSD	University of California, San Diego
UD	University of Delaware
UL	Underwriters Laboratories
V1G	Vehicle-to-Grid Communications for Charge Management
V2G	Vehicle-to-Grid
V2H	Vehicle-to-home
V2X	Vehicle-to-X
VGI	Vehicle-Grid Integration
WACC	Weighted Average Cost of Capital
WPT	Wireless Power Transfer
ZEV	Zero Emission Vehicle
ZNE	Zero Net Energy

1 Executive Summary

This report summarizes the project objectives, technical results, and lessons learned for EPIC Project 2.03b – Test Smart Inverter Enhanced Capabilities - Vehicle to Home, also referred to as EPIC 2.03b – Vehicle to Home Demonstration, as listed in the 2016 EPIC Annual Report.

1.1 Project Overview

Electric vehicle (EV)—including battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV)—adoption in California will continue to increase due to the state's zero emission vehicle (ZEV) goal calling for 1.5 million ZEVs on roadways by 2025[1]. In addition, as zero net energy[2] (ZNE) homes emerge in California, market stakeholders are expressing interest in whether EVs can serve as a backup power source during outage or demand response (DR) events. This value proposition could be achieved through a vehicle-to-home (V2H) configuration that would island a home during an outage to provide on-site resiliency or for residential DR participation (providing load drop by islanding the house). Notably, V2H is distinct from, and less complex than, a vehicle-to-grid (V2G) configuration which requires a different equipment set up and integrates an EV into the electric distribution system to provide grid support services through bidirectional power flow, rather than the unidirectional power flow of a V2H configuration. This reduced complexity could make V2H deployable sooner than V2G.

The EPIC 2.03b project was developed to complement the smart inverter assessment related to solar photovoltaics (PV) in project *2.03 – Test Smart Inverter Enhanced Capabilities* as further described in Pacific Gas and Electric's (PG&E's) EPIC 2 Application[3]. California Public Utilities Commission's (CPUC) Energy Division requested that PG&E explore expanding its EPIC Smart Inverter for PV Project to include EVs for the purpose of testing this functionality. EPIC 2.03b assesses whether "EV charging stations and on vehicle smart inverter technologies" can provide rate payer benefits such as through participation in the RA program, as requested by D.15-04-020.[4]

The project sought to demonstrate charging and discharging of the EV in response to DR or hard islanding events through multiple test modes.[5] These tests, combined with internal PG&E data, market data, and customer survey data provided PG&E with sufficient data to quantify the relevant costs and

[1] Governor's Interagency Working Group on Zero-Emission Vehicles, "ZEV Action Plan: An Updated Roadmap toward 1.5 Million Zero-Emission Vehicles on California Roadways by 2025," *State of California*, 2016, https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf.

[2] California Energy Commission, "2015 Integrated Energy Policy Report," June 29, 2016, http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-01/TN212017_20160629T154354_2015_Integrated_Energy_Policy_Report_Small_File_Size.pdf.

[3] Pacific Gas and Electric Co., Pacific Gas and Electric Company Electric Program Investment Charge Triennial Plan (2015-2017), May 1, 2014, Attachment 1, p. 44. https://www.pge.com/includes/docs/pdfs/about/environment/pge/epic/Attachment1.pdf

[4] California Public Utilities Commission, "EPIC 2 Decision (D.15-04-020)", PG&E 3. Testing of Smart Inverter Capabilities: As part of PG&E's work to ensure that it provides ratepayer benefits, this project could consider whether or how smart inverters might enable or facilitate residential distributed generation (DG) participation in the Resource Adequacy (RA) program (R.11-10-023 and its successor) as aggregated resources. Additionally, EV charging stations and on vehicle smart inverter technologies should be included within the scope of this project.

[5] Pacific Gas and Electric Company, "Electric Program Investment Charge 2016 Annual Report," *Pacific Gas and Electric Company*, Feb 28, 2017, https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/2016-EPIC-Annual-Report.pdf.

benefits of V2H to the EV owner and to utility customers ahead of future potential commercialization of V2H technology in California. The results could allow utilities to better understand:

- The viability of V2H system configurations in a lab setting.
- Whether an EV in a V2H configuration is cost effective for use during peak load (demand response) or outage conditions.
- Whether a V2H system with solar PV and stationary storage can provide benefits during sustained outage conditions.
- Customer sentiment around the technology.
- Market stakeholder viewpoints and barriers to adding the V2H functionality to their vehicles.

From a programmatic perspective, demonstrating the technical feasibility of V2H system configurations aligns with the primary EPIC principle of investigating resources that can support greater reliability; in this case, during peak load and outage conditions. Additionally, understanding potential customer interest and validating the costs and benefits of the V2H technology at a site-specific level also aligns with another primary EPIC principle of vetting the potential commercial prospects of the technology before dedicating funds to support commercialization.

In summary, the project demonstrated the technically feasibility of V2H in a variety of configurations, as well as its ability, when purchased and installed by a customer, to cost-effectively respond to a demand response event from a program administrator standpoint. However, the lack of commercially available technologies for a full V2H system in California today, in addition to the estimated high upfront cost and the low cost-benefit ratios from the customer and societal perspectives, indicates that the nascent V2H market does not warrant immediate commercialization or policy intervention until market actors address barriers. To support market actor activities, the project identified opportunities for future development to better understand the performance of various component configurations in a field setting. The project further identified current drivers and barriers to V2H technology commercialization in California and potential solutions to address the barriers. Consequently, the project results are relevant for consideration by PG&E and other utilities facing significant, near-term penetration of EVs in their service territories. The results produced by the project can be used by market actors and researchers to further investigate the commercial and financial prospects for developing business models around the V2H technology value proposition.

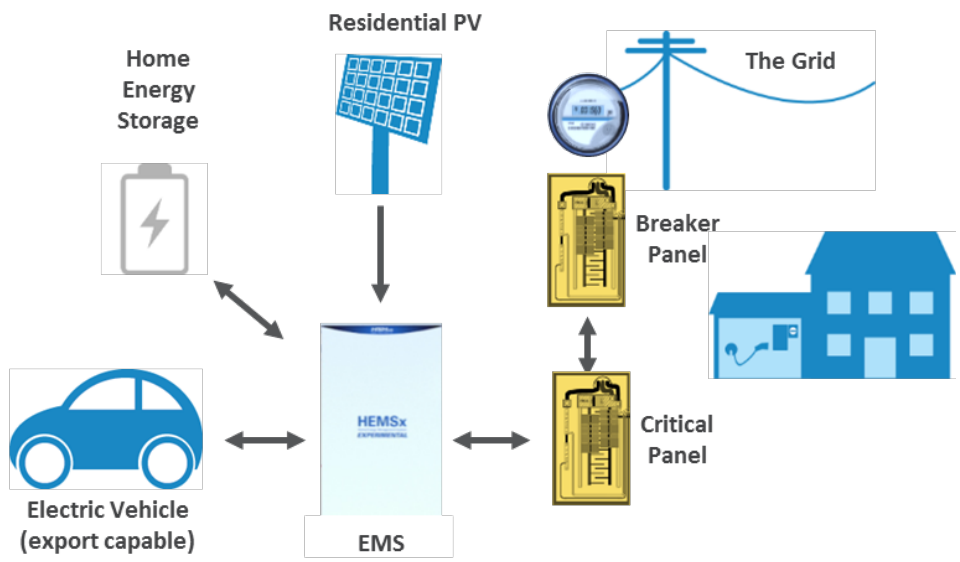
1.2 Key Objectives

The primary goal of the EPIC 2.03b project was to enable charging and discharging of the EV in response to DR or hard islanding events through multiple test modes.

In pursuit of this goal, EPIC 2.03b established the following objectives:

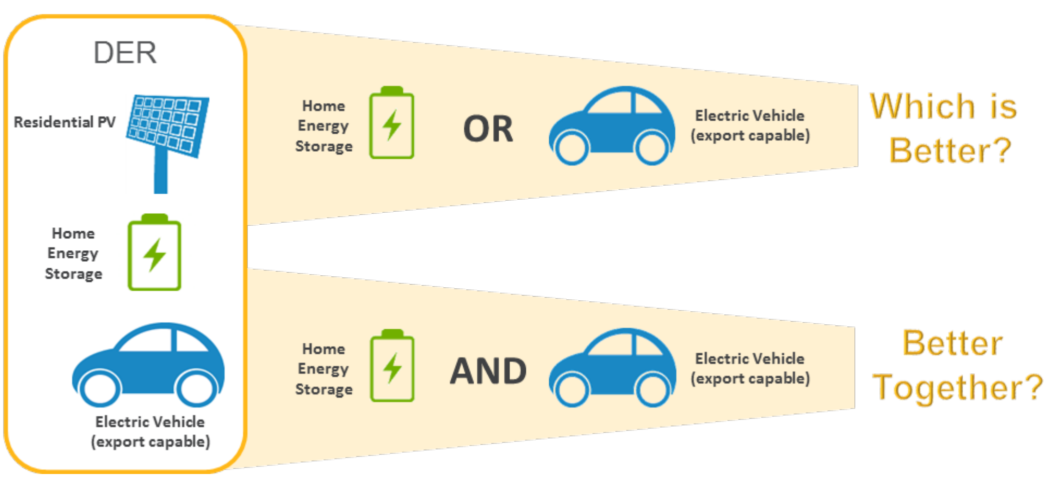
- Test the efficacy and feasibility of a bi-directional power flow EV to enable a residential customer, as depicted in Figure 1, to:
    - Respond to DR signals.
    - Support islanding (*i.e.*, support household load in the event of a grid outage).

Figure 1. Demonstration V2H System Diagram



- Evaluate the performance of the EV energy flow capabilities to support residential load during DR and hard islanding events.
- Evaluate the potential value to PG&E customers and to the utility of V2H technology.
- Investigate new and novel, or net new, concepts for PG&E customers and California market actors depicted in Figure 2, including:
    - Can a vehicle replace the hard islanding and DR functionality and benefits of a stationary storage device?
    - Are there incremental hard islanding and DR benefits from using both stationary storage and a vehicle to provide a better solution?

Figure 2. EPIC 2.03b Net New V2H Testing Questions



The report documents how PG&E accomplished these objectives. EPIC 2.03b focused on precommercial technology demonstration and directional indications of costs and benefits to customers and PG&E. The project's scope did not include developing a V2H program design, exploring potential justification for such a program, or developing communications standards and protocols for such a program. In addition, while there are a range of benefits associated with storage, this project focused specifically on the DR and outage conditions commensurate with the EPIC 2.03b project scope for the V2H technology investigation. This project also did not address submetering solutions for retail/wholesale revenue settlements or test vehicle degradation.[6]

1.3 Key Accomplishments

The following summaries cover the key accomplishments and findings of the project over its duration:

- **Clarified Technical Distinctions that Separate V2G and V2H Functionalities**

  V2H and V2G are similar in that they both require bidirectional power flow (charging and discharging from an EV battery), however V2H and V2G are different sets of functionalities and the hardware and configurations to enable them are distinct. A V2H system operates only when a home is islanded from the grid during an outage to provide on-site resiliency or for residential DR participation (providing load drop by islanding the house). V2H is distinct from, and less complex than, a V2G configuration which requires a different equipment set up and integrates an EV into the electric distribution system to provide grid support services through bidirectional power flow from and to the grid. Until an EV charger is developed that contains both types of inverters, and the ability to appropriately switch between the two, a customer would have to choose which application they wish to pursue—V2H or V2G—and commensurately select the relevant inverter type for their EV charger.

- **Characterized Technology and Market**

  Several barriers to commercialization exist for V2G and V2H technologies in the United States. OEMs are unwilling to mass produce vehicles capable of bi-directional energy flow until more testing has been completed and vehicle warranty issues are resolved. Currently, not all necessary technology is equipped to participate in grid services. From a utility standpoint, 100 kW of guaranteed minimum capacity for DR is typically required before a utility will allow new market entrants to participate in grid services. The implication for utilities and other potential V2G/V2H program administrators is the need for oversubscription to ensure adequate capacity during event calls or outages, since the mobile nature of EVs prevents 100% grid-connected availability. Based on technology barriers to V2G and V2H commercialization, the market needs continued testing, especially in residential and commercial settings. Key areas for investigation include hardware improvements that simplify and reduce costs of installation and operation, software integration with utility systems, customer awareness, customer willingness to accept participation incentives, and customer interest in other value streams such as load shifting.

- **Conducted Customer Survey on Potential for V2H/V2G Adoption**

  The project conducted a concept test survey of PG&E's Customer Voice panel to better understand consumer interest in, and motivations for, adopting V2H/V2G technology. The survey also assessed the current market potential for such a product. The survey presented

[6] Typical hybrid car warranties extend for 8 years and at least 100,000 miles. Testing vehicle degradation after 1 year of use is not likely to provide meaningful results.

400+ EV owners with the concept at a high level and successfully produced data that send clear directional signals about customer interest and willingness to pay for V2H capabilities.

- **Verified and Validated V2H System Technical Feasibility in a Lab Setting**

  Project testing was key to establishing the availability and viability of V2H technology. Scenario testing demonstrated the success of the EV to perform as a viable energy resource for the home, including integration with components involved in a V2H system configuration. The project's lab-based tests successfully demonstrated that the EV discharge was able to:

  - Perform cold load pick up and load following functions;
  - Serve as a voltage source allowing residential solar PV to generate and be utilized in islanded applications;
  - Parallel with solar PV and/or stationary storage to work in combination to provide electricity for household use;
  - Switch to charging mode and absorb solar PV generation that was in excess of household consumption; and,
  - Generally maintain voltage levels when islanded within the range of Rule 2 requirements.

1.4 Key Findings & Takeaways

The project produced the following ***key findings*** and results:

- **V2H Technology is Technically Feasible but Not Commercially Available**

  The V2H system testing execution successfully demonstrated the feasibility of the EV (with or without SS pairing) to capture excess solar PV energy, act as current and/or voltage sources, act as frequency generators to enable solar PV to function in islanded situations, and properly transfer and handle cold loads in loss of grid situations—all while generally maintaining safety and operating within utility requirements. One test failed when utility voltage requirements were exceeded; although such technology may not be subject to Rule 2, it should be developed and tested to ensure it adheres to appropriate voltage sensitivities for islanded residential use. Table 1 includes a summary of the key lab test results. Setting up the lab test as well as surveying the market determined that V2H hardware and software is not available on the market, components need to be commercialized with a focus on simplifying and minimizing installation and operation costs.

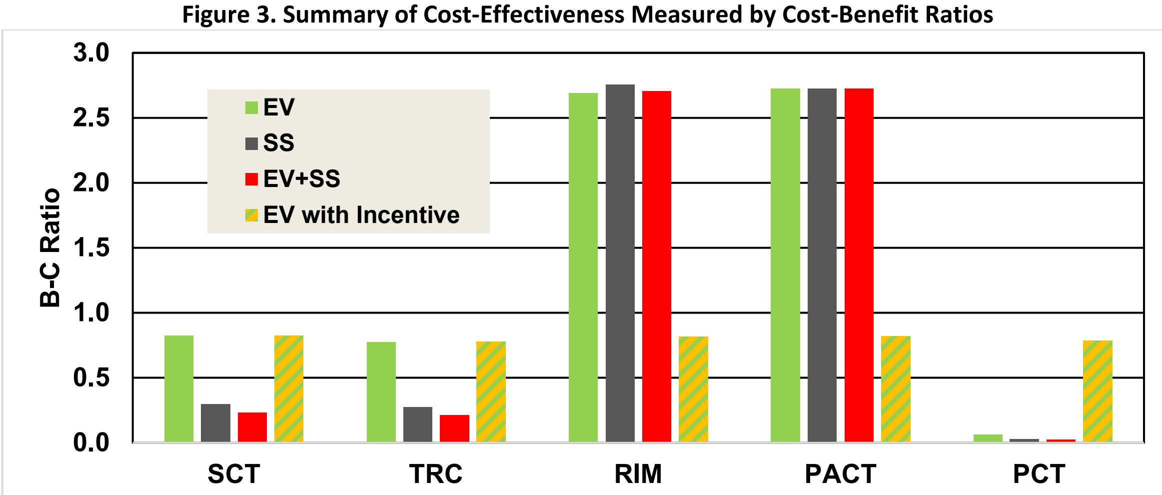
Table 1. V2H System Test Results

Scenario	Primary Resource(s)	Success Criteria Tested				
		Islanding (Outage / Demand Response)	Paralleled Resources	Cold Load Pickup	Rule 2 Voltage Range	Load Following
Verification	SS	Pass	Pass	Pass	Pass	Pass
	SS + PV	Pass	Pass	N/A	Pass	Pass
Validation	EV Islanded	Pass	N/A	N/A	Pass	Pass
	EV Islanded + Grid Support	Pass	N/A	Pass	Pass	N/A
	EV Islanded + PV	Pass	Pass	Pass	Pass (7-13) Fail (70)	Pass
	EV + SS	Pass	Pass	Pass	Pass	Pass
	Nanogrid[7]	Pass	Pass	Pass	Pass	Pass

- **Expected V2H System Costs Outweigh the Quantifiable Benefits**

  This project assessed the quantifiable V2H system cost-effectiveness by comparing the costs with the benefits of participating in PG&E's California Independent System Operator (CAISO) Supply-Side Pilot (SSP) program[8] under the five different tests in the California Standard Practice Manual to determine the value of V2H to customers, utilities, and society. The analysis demonstrated that the value of V2H varies significantly depending on the stakeholder viewpoint, the primary driver of the net benefits was the allocation of equipment capital costs among stakeholders. As shown in Figure 3, the configurations are cost-effective under the Ratepayer Impact Measure (RIM) test and Program Administrator Cost Test (PACT), but not cost-effective under the Societal Cost Test (SCT), Total Resource Cost test (TRC), and Participant Cost Test (PCT). These three tests that consider the customer perspective all produce a cost-benefit ratio of less than 1 primarily because of the upfront customer capital. A separate scenario (EV with Incentive) considered the cost-effectiveness if the customer received a $2000 incentive to install the V2H system (the *minimum* incentive level that would result in customer adoption according to the project's Customer Survey results), the benefit-cost ratio results were less than 1 for all five tests.

Figure 3. Summary of Cost-Effectiveness Measured by Cost-Benefit Ratios



- **High Customer Interest in Emergency Preparedness but Costs Outweigh Perceived Benefits**

  Interest in V2H is very high among EV Owners, as more than half said they would be very interested in the technology; however, interest significantly declines to less than 10% following presentation of the estimated price (about $4,500[9]). As mentioned, the customer survey indicated that the optimal price for a full V2H system to be around $800. Notably, at a price above $1,000 customer interest drops dramatically as consumers do not feel that the frequency of power outages justifies the expenditure.

  Respondents viewed the technology primarily as an emergency preparedness (resiliency) tool and/or a way to retain power during an outage—and to a lesser degree as a way for them to save money on their bills (only available with V2G functionality and NEM) or earn incentives (i.e. demand response participation via either V2H or V2G). While most customers have experienced multiple power outages, they tend to be infrequent and of short duration. As a result, relatively few (about one in ten) are very concerned about outages. There is a potential marketing opportunity for EV manufacturers to appeal to a small group of potential EV consumers. About 12% said they would be much more likely to consider purchasing an EV if V2H technology were available.

- **Customer Willingness to Pay Lower than Estimated V2H System Cost**

  The cost-effective result under the RIM and PACT tests rests on the assumption that a small incentive payment would be sufficient to garner customer participation in a demand response program after the customer has already adopted the V2H technology due to the outage support it can provide. This assumption was validated by the customer survey which found that the most appealing attributes of the V2H technology concept were emergency preparedness and retaining power during an outage (see Appendix G . Project results indicate there could be up to $1,389 in net benefits available to incent participation (see Table 14); however, a $1,389 participation incentive does not close the gap between the estimated price of a V2H system to the customer ($4,500[10]), and the optimal price (willingness to pay) determined in the customer survey ($800). Further, the net benefits fall below an estimated *minimum* incentive level of $2000 which would interest only the least price sensitive respondents to the customer survey. After the technology becomes commercially available, determining whether utilities and other potential program administrators should develop programs encouraging adoption of V2H systems may require further investigation into customer awareness, willingness to accept participation incentives, and interest in other value streams, such as load shifting.

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[9] Estimated full cost of V2H system (technology and installation, but not the cost of an export capable EV) is higher than the incremental cost value used for the cost benefit analysis as explained in Section 3.4 . The survey tested customer reaction to estimated full system cost even for customers who already have level 2 charging installed, because V2H implementation will require all new hardware.

[10] The cost estimate used in the customer survey for a V2H system includes a hypothesized bi-directional charger and installation cost of $2,400 (Table 10) as well as estimated critical panel costs (transfer switch, panel equipment, switch box) and installation of $2,100. Critical panel costs are hypothesized based on anecdotal market-based quotes obtained by PG&E for the purposes of the customer survey. There is a high degree of uncertainty in the estimate due to the lack of a commercially available bi-directional charger, and therefore, a lack of procurement and installation experience by the supply chain for a full V2H system. The figures used are intended to provide directional results until the technology achieves commercialization in the California market, and better data become available for further analysis.

- **V2H Commercialization is Challenged by Multiple Barriers**

  The cost-benefit analysis and the market and regulatory assessment identified barriers and drivers to V2H commercialization. Key barriers to V2H commercialization identified by the project's research and market stakeholder interview activities include cost, unclear path to resolve battery warranty issues (currently V2H or V2G export voids warranty), value capture limited with V2H functionality, standards implementation, and V2H arriving second to market behind stationary storage. While the barriers are currently impeding the commercialization progress of V2H technologies, several potential solutions include partnerships between stakeholders; increasing value capture; and scaling beyond individual systems to reach market-ready products. A summary of challenges and potential solutions are provided in Table 2.

Table 2. V2H Commercialization Barriers and Potential Solutions

Barrier	Description	Potential Solution
Vehicle Regulations Tied to Historic Market Approach	Current vehicle warranty policy dictated by regulations is based on time and/or miles.	OEMs receive support to update the warranty regulations.
Capital Costs	V2H is not cost-effective except from a program administrator perspective, without a participation incentive, because benefits are small relative to upfront capital costs.	Develop market or government regulatory mechanisms to minimize costs by increasing scale (*e.g.*, subsidies, resource aggregation, increased capacity requirements), which creates a better value proposition. Reduce upfront costs to maximize the long-term benefit of the service.
Limited Value Capture Opportunities for V2H on Reliable Grids	Low incremental value of V2H to reliable grids. This is because V2H's resiliency has an inverse relationship between ability to capture value versus resilience/uptime of the existing grid.	Improve value capture by investigating technology that can provide both V2H and V2G services, rather than solely V2H, in problematic system locations (*e.g.*, issues with congestion, voltage, frequency) to maximize system flexibility/resilience as well as reliability in a more cost-effective manner.
Solution Deployment Requires Unique Negotiation Each Time	Need to align market actors on methods to execute V2G/V2H standards.	Identify appropriate clearinghouse body to facilitate alignment on standard and protocol issues impacting commercialization. Broader commercialization requires a higher-level body like FERC/NERC, ISOs, or RTOs rather than more granular utility or state levels.
DER Competition Within Same Solution Space	Stationary storage, DR, Solar PV systems each offer a viable alternative and are already commercially available. Additionally, while vehicle-based solutions can have lower costs, they also have lower availability.	Market actors can drive V2G competitiveness by focusing on scaling beyond individual systems to maximize value streams and communicating to customers the cost competitiveness if barriers are surmounted to increase adoption.

Based on the key findings and results, PG&E identified the following ***key takeaways*** and lessons learned from this project:

- **Key Question: Home Energy Storage or Electric Vehicle?**

  Answer: V2H system may be able to substitute for stationary storage, depending on customer mobility and home electricity needs.

  The project found that an EV-only V2H system can replace the hard islanding and DR functionality of a stationary storage device, and provide greater net benefits *when the EV is connected to the system and at suitable level of charge*. However, the overall net benefits to an individual customer will depend on that customers' mobility and household electricity needs at the exact moment of an outage or DR event. For example, if an outage occurs while the EV is away from home, a single customer may not care about the loss of their V2H resiliency benefit because both they and the EV were away from home during the event. Conversely, a customer who is away from home, but has other household members at home during the event, may not value the outage support of the EV as highly as SS because the resiliency benefit of V2H functionality is not available to the non-driving household members when the EV is not at home. PG&E expects that real-world field results will vary based on a host of conditions including V2H system setup, selected hardware, customer objectives, etc.

- **Key Question: Home Energy Storage and Electric Vehicle?**

  Answer: V2H system with solar PV and stationary storage can provide significant resiliency benefits in the case of sustained outages.

  The project found that a V2H system with solar PV and stationary storage provides significant, compounded resiliency benefits to the site owner in the case of sustained outages. The analysis showed that combining both solar PV and stationary storage systems provided enough storage for the solar PV system to be effective in recharging the stationary storage during the day for use at low/no solar availability, such as at night. With the combined system, the additional storage capacity enables the V2H system to serve household load for multiple days—even during the summer—and approaches multi-week coverage during high solar/low demand times, like the shoulder seasons. However, this resiliency benefit will need to be balanced with mobility needs. Notably, these incremental benefits come at a significant incremental cost to the V2H system owner due to the upfront costs of the system components related to both the EV and SS. Also, it is not clear whether the additional resiliency hours for the site owner translate into value for the utility or society. PG&E expects that real-world field results will vary based on a host of variables including V2H system setup, selected hardware, customer objectives, etc.

- **Once V2H/V2G technology is commercially available, early adoption is likely to be motivated by V2H resiliency and reliability benefits.**

  In the customer survey, when customers considered the functionality of both V2H and combined V2H/V2G systems they were significantly more interested in the V2H functionalities of being prepared in case of an emergency and retaining power during an outage than in functionalities that involved interacting with the grid. This finding indicates that business models built to offer V2H functionality are likely to gain early traction over V2G-focused business models. The finding further indicates that V2H benefits will accrue primarily to individuals, at least in the initial adoption stages. However, this early adoption market may be small as only 12% of customers indicated they were very concerned about outages.

- **After a V2H system is adopted by a customer for personal resiliency and reliability benefits, utilizing an EV and V2H system for a demand response event is cost-effective from a program administrator cost test perspective.**

  The testing of new, unproven technology is an important process for the cost-conscious utility. The cost-benefit analysis performed for this project indicates that using an EV to respond to a demand response event is a cost-effective program when considering the demand response capacity benefits to a program administrator; however, it is only cost-effective under this test if the customer bears the equipment capital costs of the EV-only V2H system. In PG&E's

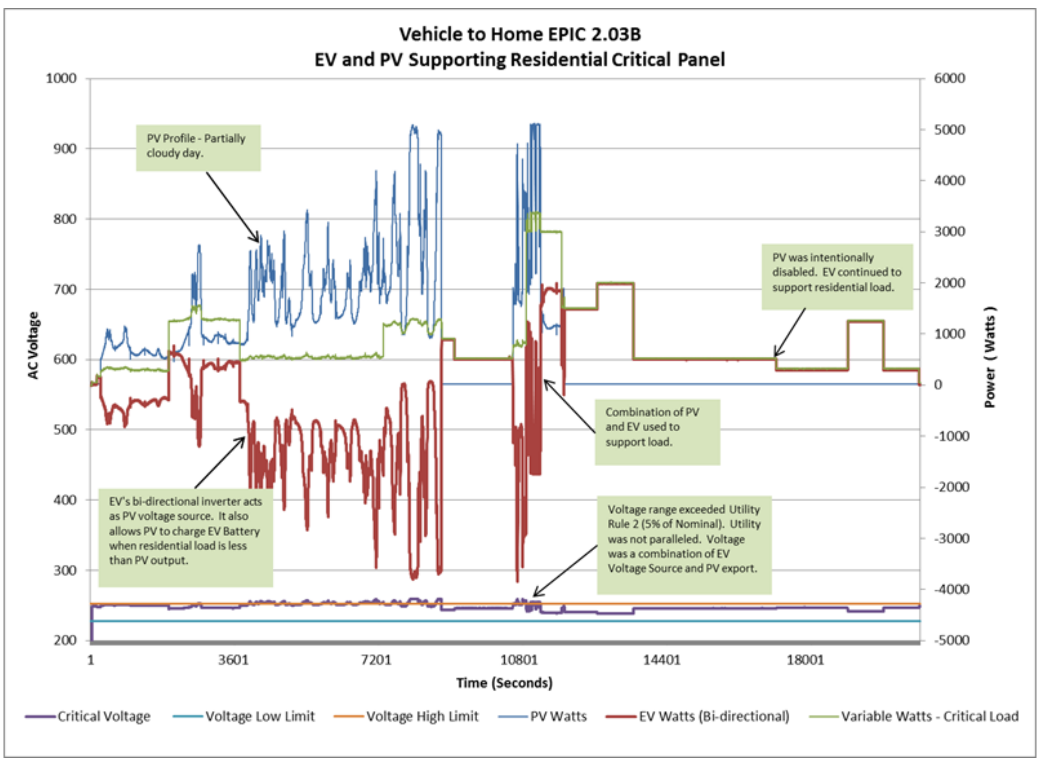
survey, customers indicated that the reliability and resiliency benefits were their primary interests in the technology. Once a customer has adopted a V2H system to gain these personal benefits, enrollment in a utility program can bring additional value. PG&E expects that the value of reliability and resiliency will vary for individual customers and that real-world cost results will vary based on a host of variables including V2H system setup, selected hardware, customer objectives, etc.

1.5 Challenges and Resolutions

- **Opportunity for Further Testing**

  In Test 70, while the EV and PV demonstrated the ability to support critical variable load while in parallel with the EV for a 5-hour test period, EV voltage did exceed Utility Rule 2. Test data indicated the distribution of power between EV and PV such that, as residential load decreased, the EV would absorb any additional power from the PV. If EV state of charge (SOC) was 100%, and not able to accept power from the PV, the PV demonstrated its ability to trip. While this finding did not present a challenge to the demonstration project, it did identify an opportunity for additional testing of large PV load impacts on V2H system voltage. Figure 4 illustrates this test condition in detail.

Figure 4. Islanded Home with EV in Voltage Source Mode with PV and Varying Critical Loads



1.6 Key Recommendations

The following summary of key recommendations is of interest to PG&E and the wider utility industry:

- ***Research* – Conduct additional investigations to address barriers in nascent V2H market ahead of policy interventions.**

  The lack of commercially available technologies for a full V2H system in California today, and the low cost-benefit ratio results from the customer and societal perspectives demonstrate that V2H is still a nascent market in the state. If market actors can overcome the barriers identified through this project, and develop business models proven to provide benefits to the customer, utility, and society, PG&E and other utilities can investigate the following deployments:

  - Enroll residential customers that have V2H technology in applicable DR programs.
  - Provide hardware and services to residential customers to allow for DR participation or independent islanding.

- ***Policy* – Early adopters of V2H are likely to be motived by individual benefits, spurring a need for policy discussions on V2H to recognize that publicly funded incentives are not likely to accrue benefits to other ratepayers or society.**

  The customer survey indicates that interest in V2H technology is primarily motivated by the desire for resiliency and reliability benefits. If the V2H technology is primarily used for those purposes rather than for participation in DR programs, the benefits will mainly accrue to the individual customer rather than ratepayers or society as a whole. Therefore, future policy and program design must consider what, if any, level of subsidization for customer installation V2H technology is appropriate.

- ***Technology* – Investigate optimal system configurations from all cost test perspectives for all system configurations (EV, SS, EV+SS) through a field test of V2G/V2H technology with a market actor partner in PG&E's CAISO SSP program.**

  Additional investigation into cost-effectiveness while ascertaining actual interconnection, performance, and customer participation data would aid in understanding: the incremental value of connecting both the main and critical panels; V2H product development to enhance DR event capacity offerings; and benefits incremental to DR/outage.

  For example, currently V2H requires off-board hardware to handle transfer switch functions for isolating in islanding mode. In the future, the ability to use AC ports as well, and on-board hardware that includes more functionality—such as handling transfer switch functions—could achieve further cost reductions. Such research could explore a potential policy or market intervention to leverage the vehicle's DC connection for power export capabilities. This intervention would require that a stakeholder incur the cost of external equipment to overcome the designed limited functionality[11] of current vehicle hardware used for power export. Notably, the stakeholder that incurs this equipment cost would address the capital cost barrier by allowing the equipment specifications and standardization to evolve on a track independent of the vehicle's lifecycle, thereby providing flexibility that could support V2H/V2G commercialization.

[11] Automakers must tradeoff technology capability, cost, and market readiness when selecting on-board equipment relevant for power export as identified in stakeholder interviews described in 4.1.1 .

- ***Benefits* – Investigate value of resiliency to the customer as well as customer load during periods of long sustained outages.**

  The completed testing for EPIC 2.03b incorporated short-term outages. To better understand the value of resilience to the customer, PG&E recommends further testing and investigation take place to analyze longer-term outages. Questions to address include: what is a customer's willingness to pay for resilience, and what conservation behaviors can we expect during long-term outages?

- ***Benefits* – Investigate additional system benefits that would be produced if bi-directional chargers capable of both V2H and V2G were available and whether network effects could increase these benefits.**

  If bi-directional chargers capable of both V2H and V2G are available and garner customers interest, the potential to utilize V2G is possible; however, further testing and investigation is required. Market actors can drive V2G competitiveness by focusing on scaling these systems to maximize value streams and communicating the value proposition to customers, if barriers are surmounted, to increase adoption.

- ***Costs* – Investigate policy or market intervention opportunities to minimize upfront capital costs to make V2H cost-effective from a customer perspective.**

  The nascent V2H market would benefit from developing market or government regulatory mechanisms to minimize costs by increasing scale to help create a better value proposition for V2H technology. Reducing upfront capital costs could maximize the cost effectiveness of V2H. The customer survey indicates that an optimal price of around $800 for total V2H system set up, though current estimates exceed that by 4-5 times.

- ***Standards* – Investigate opportunities to align market actors and governing standards bodies on methods to execute V2G/V2H standards.**

  Identifying an appropriate clearinghouse body to facilitate aligning standard and protocol issues impacting commercialization would streamline standards implementation. Broader commercialization requires a higher-level body (*e.g.*, FERC/NERC, ISOs, or RTOs) rather than more granular utility or state level entities.

1.7 Conclusion

As a result of the EPIC 2.03b project, PG&E has accomplished its objectives and gained additional insights into the technical feasibility and potential value of V2H technology during peak load and outage conditions. Although the project successfully demonstrated the technical feasibility of a V2H system, and determined that utilizing it as a demand response resource could be cost effective from a program administrator perspective, V2H is a nascent market and the technology is not ready for PG&E to proceed with commercialization activities. This conclusion stems from the lack of commercially available technologies for a full V2H system in California today, the high estimated upfront cost, and the low cost-benefit ratio results from the customer and societal perspectives. These results indicate that the nascent V2H market requires further investigation to better understand optimal approaches to address cost and other market barriers ahead of policy intervention.

In the interest of investigating optimal approaches, the primary recommendation of this EPIC project is to plan and execute a field test of V2H technology with a market actor partner in PG&E's CAISO SSP program. This effort would seek to test optional system configurations while ascertaining actual interconnection, performance, and customer participation data. The investigation would further test the value of resilience to the customer over short and long-term outage durations. In undertaking these areas of investigation, this effort would further inform the viability of commercializing V2G/V2H technology and understanding its potential benefits for electric ratepayers and load serving entities from all cost test perspectives.

The project also proposes investigations of potential solutions to address V2H market barriers. The customer survey demonstrates that the upfront capital cost will be a significant barrier. The project recommends investigating methods to lower that cost, such as whether alternate charger technology that leverages the vehicle's DC connection for power export, could be less costly. Finally, the project recommended identifying an appropriate clearinghouse to facilitate market actor alignment on consistent methods for executing existing and emerging V2H-related standards and protocols.

Notably, the project demonstrated that the requisite demand response mechanisms and processes with sufficient flexibility to realize benefits from resources like V2H systems, once they are available and affordable, exist in California. In particular, the flexibility provided by the PG&E CAISO SSP program that allows market actors to offer and aggregate commercially viable resources relative to electric system needs, provides a viable venue for fostering the V2H market. If market actors can overcome the barriers identified through this project and develop business models that improve the cost-effectiveness of the technology, and the affordability of residential electricity, PG&E's programs will support deployments.

Ahead of such deployments, partnerships among automakers, energy aggregators, charging networks, utilities, and mobility providers could help to advance the market; though this is expected to be challenging initially due to lack of business model clarity and uncertainty around which stakeholders will play complementary or competing roles. Decisions will pivot on the relevance of V2H capabilities to global transportation industries. Ultimately, finding these partnership opportunities, implementing aligned market entry strategies, and building sustainable business models will be critical to unlocking and capturing the V2H value streams.

PG&E's work to validate the feasibility and potential value of V2H technology has significance for the entire industry—in particular, for utilities that are experiencing customer interest in using the same technology. These findings will be shared with other utilities at industry conferences, events, and technical forums.

2 Introduction

This report documents the EPIC 2.03b – Test Smart Inverter Enhanced Capabilities - Vehicle to Home project achievements, highlights key learnings from the project that have industrywide value, and identifies opportunities for Pacific Gas and Electric (PG&E) to leverage this project for future testing.

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this technology demonstration and deployment program. The CPUC initially issued D. 11-12-035, Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level,[12] which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued D. 12-05-037, Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020,[13] which authorized funding in the areas of applied research and development (R&D), technology demonstration and deployment (TD&D), and market facilitation. In this later decision, the CPUC defined TD&D as, “The installation and operation of precommercial technologies or strategies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments to enable appraisal of the operational and performance characteristics and the financial risks associated with a given technology.”[14]

The decision required the EPIC program administrators[15] to submit triennial investment plans to cover 3-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. On May 1, 2014, in A.14-05-003, PG&E filed its second triennial EPIC application at the CPUC for the 2015-2017 cycle, requesting $48,500,000, including funding for 30 TD&D projects.[16] On April 15, 2015, in D.15-04-020, the CPUC approved PG&E’s second triennial EPIC plan, including $48,500,000 for 31 projects in this program category. Pursuant to PG&E’s approved EPIC triennial plan, PG&E initiated, planned, and implemented the following project: EPIC 2.03b – Test Smart Inverter Enhanced Capabilities - Vehicle to Home. Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the project’s progress. The following is PG&E’s final report on this project.

[12] California Public Utilities Commission, “Phase 1 Decision Establishing Interim Research, Development and Demonstration, and Renewables Programs Funding Levels,” *California Public Utilities Commission,* December 15, 2011, http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF.
[13] California Public Utilities Commission, “Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020,” *California Public Utilities Commission,* May 24, 2012, http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF.
[14] Ibid.
[15] “Program administrators” includes PG&E, San Diego Gas & Electric, Southern California Edison, and the California Energy Commission.
[16] Pacific Gas and Electric Company, “Electric Program Investment Charge Triennial Plan (2015-2017),” *Pacific Gas and Electric Company,* May 1, 2014, https://www.pge.com/includes/docs/pdfs/about/environment/pge/epic/Attachment1.pdf.

3 Project Summary

3.1 Issues Addressed

Electric vehicle (EV)—including battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV)—adoption in California will continue to increase due to the state's zero emission vehicle (ZEV) goal calling for 1.5 million ZEVs on roadways by 2025[17]. In addition, as zero net energy (ZNE) homes emerge in California, market stakeholders are expressing interest in whether EVs can serve as a backup power source during outage or demand response (DR) events. This EV functionality alone, or in combination with a residential stationary storage battery or solar photovoltaic system, could enhance the value proposition of ZNE homes to customers as the state looks to adopt standards for ZNE Code Buildings. [18]

This value proposition enhancement is particularly relevant for a vehicle-to-home (V2H) configuration that would be appropriate for residential DR participation, or to island a home during an outage to provide on-site resiliency. Notably, V2H is distinct from a vehicle-to-grid (V2G) configuration which integrates an EV into the electric distribution system to provide grid support services through bidirectional power flow, rather than the unidirectional power flow of a V2H configuration as detailed in Section 3.4 . V2G configurations are currently undergoing precommercial hardware testing in various U.S. jurisdictions, with potential business models leveraging net energy metering (NEM) that could be more compelling than V2H systems. Because V2H configurations only provide on-site power flow without NEM, the necessary hardware and standards are less complex and therefore potentially more quickly implementable in California than V2G configurations as detailed in Section 4.1.4 . Industry stakeholders and customer interest also indicate that V2H configurations are likely to be available and demanded sooner than V2G configurations.

Consequently, the primary issue the project sought to address was to understand whether V2H system configurations can function in accordance with existing standards, protocols, and regulations to produce benefits for various California stakeholders ahead of potential commercialization. To achieve this understanding, the project sought to demonstrate charging and discharging of the EV in response to DR or hard islanding events through multiple test modes.[19] These tests, combined with internal PG&E and market data, stakeholder interviews, and customer survey data, provided PG&E with sufficient data to quantify the relevant costs and benefits of V2H to the EV owner and to utility customers ahead of future potential commercialization of V2H technology in California.

[17] Governor's Interagency Working Group on Zero-Emission Vehicles, "ZEV Action Plan: An Updated Roadmap toward 1.5 Million Zero-Emission Vehicles on California Roadways by 2025," *State of California*, 2016, https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf.
[18] California Energy Commission, "2015 Integrated Energy Policy Report," June 29, 2016, http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-01/TN212017_20160629T154354_2015_Integrated_Energy_Policy_Report_Small_File_Size.pdf.
[19] Pacific Gas and Electric Company, "Electric Program Investment Charge 2016 Annual Report," *Pacific Gas and Electric Company*, Feb 28, 2017, https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/2016-EPIC-Annual-Report.pdf.

3.2 Project Objectives

The primary goal of the EPIC 2.03b project was to complement the 2.03 solar photovoltaics (PV) smart inverter assessment proposed in PG&E's EPIC 2 application by assessing EV-related technology. This expanded scope was requested by the CPUC as part of D.15-04-020 after the initial PV smart inverter project was already significantly scoped. Furthermore, PG&E determined that use cases and technology maturity for EV inverters and PV smart inverters were sufficiently different to warrant separate projects.

Initially, PG&E investigated performing a field demonstration of V2H functionality. Though a relevant technology vendor and a customer site were identified, PG&E determined that the project was not viable for field testing because the vendor could not provide a vehicle capable of bi-directional energy flow (charging and discharging) within the timeline necessary to complete the project. Consequently, PG&E determined that it needed a test facility demonstration to achieve the project goals within the EPIC 2 timeframe. To that end, PG&E's Advanced Technology Solutions (ATS) group installed a V2H demonstration site at its test facility in San Ramon, California. The ATS installation included the following:

- EV with export capabilities[20]
    - PG&E fleet plug-in hybrid electric truck, modified by ATS for bi-directional power flow in direct current (DC) export mode
    - 60 kWh, 5 kW (Max DC export mode)
- Solar PV system rated at 5 kW
- Residential-sited stationary storage system rated at 5 kW, with total capacity of 8.6 kWh

The project approach to expanding PG&E's Smart Inverter for PV Project to include EVs was to demonstrate V2H technology by:

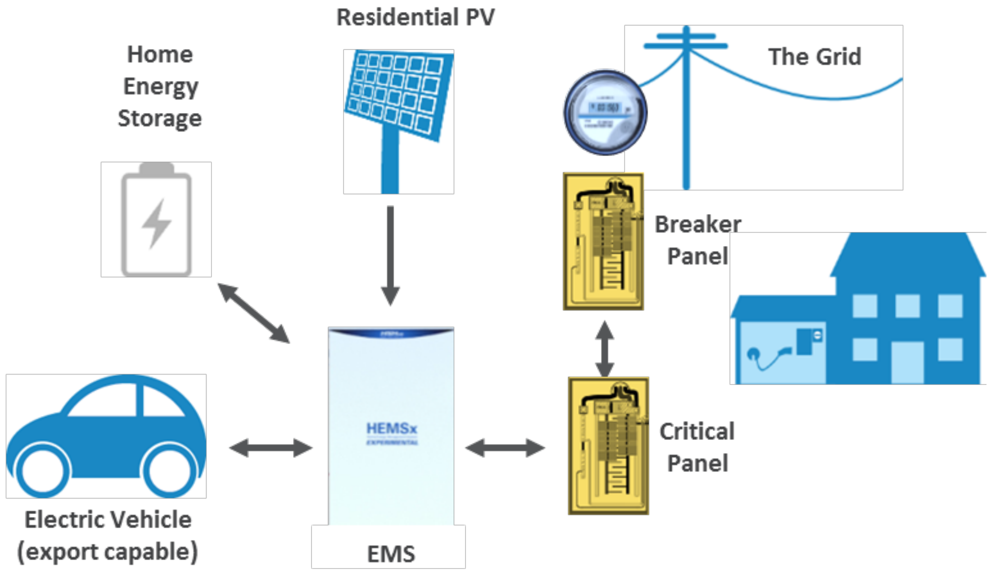
- Investigating whether a bi-directional power flow EV, combined with residential-sited storage (stationary storage) and solar PV, can power a customer's home during a DR event or outage
- Assessing the customer benefits of V2H

Through the EPIC 2.03b V2H system depicted in Figure 5, PG&E tested the efficacy and feasibility of a bi-directional power flow EV to enable a residential customer to:

- Respond to DR signals
- Support islanding (*i.e.*, support household load in the event of a grid outage)

[20] An energy management system (EMS) was simulated by ATS for demonstration purposes; however, the functionality of a EMS is assumed to be part of any commercial V2H system because the bi-directional charger and/or stationary storage would serve this function for the V2H system. Consequently, the cost-benefit analysis assumed that the technical function of coordinating various V2H system components, typically performed by an EMS, is performed by any one of the key V2H system components (i.e., EVSE or SS), depending on the particular system configuration (e.g., EV-only scenario assumes EVSE has EMS functionality, while SS-only scenario assumes SS has EMS functionality)."

Figure 5. Demonstration V2H System Diagram



The project further sought to evaluate the performance of the EV charging and discharging capabilities to support residential load during DR and hard islanding events. PG&E's ATS group performed the tests at its test facility in San Ramon, California. ATS activities included the following:

- Constructing a residential-scale system with SS, solar PV, and an EV modified for bi-directional power flow at the ATS lab
- Integrating the system with a load bank that simulated residential load profiles
- Testing both hard islanding and DR capabilities of the energy resources against a variety of residential load scenarios
- Monitoring device performance independently using current, voltage, and power meters to assess the volume of residential load or DR requirements that can be provided by output from the devices under various scenarios

PG&E used the performance results alongside market data and internal data to evaluate the potential value to PG&E customers and to the utility of V2H technology, as tested by PG&E's ATS group. The subsequent cost-benefit analysis included:

- Analyzing the results from the DR and hard islanding tests
- Determining the potential value of V2H technology to customers and the utility
- Determining the potential magnitude of any associated ratepayer benefits if/when bi-directional EVs become commercially available

Finally, PG&E's EPIC 2.03b project sought to investigate new and novel, or net new, concepts for PG&E customers and California market actors by testing multiple residential load pattern use cases for bi-directional power flow of an EV to enable hard islanding at a residential location. While the market assessment project activity identified that these concepts had been addressed in prior research, PG&E uncovered two untested research questions that the project was well-positioned to address. The two net new research questions that were identified during the market assessment, added to the project objectives, and addressed in the work process include:

- Can a vehicle replace the hard islanding and DR functionality and benefits of a stationary storage device?
- Are there incremental hard islanding and DR benefits from using both stationary storage and a vehicle to provide a better solution?

EPIC 2.03b focused on precommercial technology demonstration and directional indications of costs and benefits to customers and PG&E. The project's scope did not include developing a V2H program design, exploring potential justification for such a program, or developing communications standards and protocols for such a program. In addition, while there are a range of benefits associated with storage, this project focused specifically on the DR and outage conditions commensurate with the EPIC 2.03b project scope for the V2H technology investigation. PG&E recognizes while there are many other potential benefits to examine as detailed in Section 4.4.3 , including additional examinations required more time than was allotted for V2H demonstration installation, testing, analysis, and reporting. This project also did not address submetering solutions for retail/wholesale revenue settlements or test vehicle degradation.[21]

3.3 Scope of Work and Project Tasks

The EPIC 2.03b project consisted of five tasks, including: 1) a market and regulatory assessment; 2) V2H demonstration setup, test plan, and testing; 3) cost-benefit analysis framework; 4) cost-benefit analysis results; and 5) commercial business model analysis.

Task 1: Market and Regulatory Assessment

This task included various market and regulatory analyses that informed developing the V2H Test Plan, administering market stakeholder interviews and a customer survey, as well as all subsequent analyses of V2H costs and benefits to customers and the utility.

Key Deliverable:

- V2H Market and Regulatory Assessment
- V2H Stakeholder Interview and Customer Survey Results

Task 2: V2H Demonstration Setup, Test Plan, and Testing

This task established the lab testing plan setup, approach, and timeline. The goal was to identify any component issues that would prove a barrier to commercialization, such as potential handoff issues among components or testing parameter failures due to exceeding utility and safety guidelines.

Key Deliverable:

- V2H Demonstration Test Plan and Results

Task 3: Cost-Benefit Analysis Framework

This task established a framework for comparing costs and benefits of V2H technology based on the Task 1 findings.

[21] Typical hybrid car warranties extend for 8 years and at least 100,000 miles. Testing vehicle degradation after 1 year of use is not likely to provide meaningful results.

Key Deliverable:

- V2H Cost-Benefit Analysis Framework

Task 4: Cost-Benefit Analysis Results

This task executed the framework to perform a multi-perspective cost-benefit analysis of V2H system performance in DR and islanding conditions during an outage.

Key Deliverable:

- V2H Cost-Benefit Analysis Results

Task 5: Vehicle-to-Home Commercial Value Proposition

This task included a commercial value proposition analysis that drew from the results of all prior tasks to identify the drivers, barriers, and needed solutions for commercializing V2H technology in California.

Key Deliverable:

- V2H Commercialization Assessment

3.4 Vehicle-to-Home Overview

This section provides an overview of the V2H concept for stakeholders that are new to the concept by answering four key questions based on project findings derived from sections throughout this report:

1. How does V2H compare to V2G?
2. What does it take to install V2H, and what does it provide to a customer's house?
3. How viable and valuable is V2H?
4. What will it take to make V2H commercially available?

In summary, EPIC 2.03b demonstrates that a customer can utilize an export-capable EV today to sell energy and other energy services during peak electric system load conditions, and to support household load when the grid is down. The project demonstrated that an EV combined with the required electrical technology installed in the home (critical panel[22] and main panel transfer, inverter and EVSE with two-way capable power flow), can be a viable reliability solution. The project also identified commercially available components to develop a V2H system today. From a commercialization perspective, a V2H program could be cost effective without incentives or subsidies from a program administrator perspective; however, certain standards and regulatory matters need to be addressed first.

[22] Note that a second panel serving "critical loads" and connected to the V2H system components was used for EPIC 2.03b. A Critical Panel was sized to handle "must have" customer loads in the event of an outage, and included isolation capabilities (*i.e.*, transfer switch) commensurate with current interconnection requirements under Rule 21 to prevent a reverse power condition from the V2H system. This panel is the core subset of the home's load that gets energy from the V2H setup. In this setup, the Main Panel is not energized directly. Notably, the proposed setup reduces the cost of inverter components by reducing the load volume to invert through a Critical Panel.

1. How does V2H compare to V2G?

Vehicle-to-Grid and Vehicle-to-Home

While V2G and V2H utilize similar standards, technology, and infrastructure requirements the two applications for electric vehicles have significant differences.

From a technical point of view, a key difference is the type of inverter used by each system. Because a V2G system must parallel utility service to participate on demand in bidirectional grid services, it utilizes a "Current Source" inverter that relies on the existing voltage and frequency of the grid. Conversely, because a V2H system seeks to isolate from grid service, it relies on a "Voltage Source" inverter that generates its own voltage and frequency. While an inverter capable of both functions is technically possible, charging equipment with this capability has not been commercially developed and certified for mass market availability. Therefore, it is likely that customers will have to choose which functionality they want (either or, not both) when purchasing and installing their charger.

From the customer point of view, a key difference is that V2G is a grid-focused service with the primary purpose of generating revenue for the vehicle owner. Conversely, V2H applications are focused on the concept of islanding, or separating from—rather than serving—the grid, for the purposes of on-site resiliency and reliability during a planned or unplanned outage. This distinction between serving the home load conditions (V2H) versus serving the grid load conditions (V2G) is a core functional distinction between the two systems.

The following section provides a detailed comparison of V2G and V2H system setups that includes other important differences and similarities between the systems.

2. What does it take to install V2H, and what does it provide to a customer's house?

V2H/V2G Key Components

V2H/V2G systems generally require several key technologies and capabilities:

- **Distributed energy resources (DER)** that provide some onsite DC power (EV, stationary storage and/or solar PV), requiring an inverter to convert DC to AC power.
- **Communication capability** between DER and grid/home via an energy management system (EMS)—or equivalent equipment—providing a method to coordinate the DER, and manage the customer's needs and services provided.
- **System isolation capability** from grid connection to enter islanding mode; additional configurations could provide power back to the grid for V2G use cases with appropriate system components.
- **Bi-directional power flow capability** for each component in the V2H/V2G system.

Technical Differences between V2H/V2G Systems

The key technical differences between a V2H system, like the system developed for EPIC 2.03b, and a V2G-capable system are as follows:

- A ***V2H system*** uses a "Voltage Source" inverter type that generates its own voltage and frequency as a standalone system. Although these parameters are predetermined and configured by the manufacturer, the output would approximate what the utility would provide to a residence (*i.e.*, voltage at 240-volt AC and frequency at 60 Hz). The EPIC 2.03b V2H system utilized a bi-directional inverter. The inverter provides seamless conversion of the DC sources to AC power to be used by the home and vice versa in a reverse power flow situation. Notably, a communication protocol would need to be determined to allow safe and proper control of the EV's charge and discharge functions via the EV's on-board control system / battery management system.

- A ***V2G system*** uses a "Current Source" inverter type that relies on an existing voltage source and frequency generator (*e.g.* the utility). Without a voltage source, a V2G system with a current source inverter could not source energy. A V2G inverter would likely be external to the vehicle based on today's industry approach rather than internal to the vehicle. Interfacing to the vehicle would require a cable assembly electrically rated to accommodate the vehicle's traction battery. Like the V2H system, a communication protocol would need to be determined to allow safe and proper control of the EV's charge and discharge functions via the EV's on-board control system / battery management system.

A third option—a combined V2H/V2G system, details for which appear in Table 3 below—could be developed with certain additional, but currently commercially unavailable, components[23]. This setup would include connecting an inverter directly to the EV traction battery using the DC cables typically used for charging the EV. The addition of a transfer or qualifying switch is also necessary to provide the protection required to connect with the utility. Using this proposed setup, power would be sourced to a home's Critical Panel only. Consequently, in the event of utility service outage, such a setup would support the Critical Panel to provide V2H functionality. By extension, the EV could also export power to the Main Panel by closing a switch between the panels to join the loads into the same electrical network. If all loads on the Main Panel were met[24], this customized inverter (connected to the EV DC cables) would also then source power to the utility, past the Point of Common Coupling (PCC) to provide V2G functionality.

Table 3 provides an in-depth comparison in the California context of the key—not comprehensive—technical, regulatory, and commercial differences between three types of systems: V2H; V2G; and combined V2H/V2G.

[23] While the cables and hardware required to perform these tests were procured for EPIC 2.03b, these components were not incorporated into the vehicle because the manufacturer did not grant PG&E approval to access the EV's traction battery without voiding the warranty.

[24] Assumes main panel load does not exceed the max output of the inverter.

Table 3. Comparing V2H, V2G, and V2H+V2G Systems

	V2H System	V2G System	V2H + V2G System
Technical			
Inverter Type	Voltage Source	Current Source	Both ***Voltage + Current Source Inverters with <u>transfer switch</u>*** to shift between inverters as needed (EV connected to both)
Inverter Location	If on-board EV: 240-volt AC power cable If off-board EV: DC power cable rated for maximum traction battery capabilities		
Panel Configuration	Critical Panel needed for islanding (EV connected to Critical Panel)	No Critical Panel needed (EV connected to Main Panel)	Both ***Main + Critical Panels with <u>transfer switch</u>*** to shift between panels as needed (EV connected to Critical Panel)
Communication Capability	EMS coordinating system components and grid isolation	EMS coordinating system components and grid services participation	EMS coordinating ***<u>system components</u>***, ***<u>grid isolation</u>***, and ***<u>services participation</u>***
Communication Protocol	Developed but not yet implemented in CA[25]	Developed but not yet implemented in CA	Developed but not yet implemented in CA
Regulatory			
Interconnection Standards	IEEE 1547 CA Rule 21[26] UL 1741	IEEE 1547 CA Rule 21 UL 1741	IEEE 1547 CA Rule 21 UL 1741
Commercial			
Inverter Available	Yes[27]	Yes[28]	No
Ideal Customer Application	Off-grid	On-grid	Off-grid or On-grid

For the EPIC 2.03b tests, ATS modified and built two EVSE systems. The primary EVSE was connected to the home critical panel allowing bi-direction power flow. The secondary EVSE was used on the vehicle side to act as the transfer switch, allowing ATS to isolate the J1772 EV Connector and the external port for power export. Communication and operation were completed using an external power supply and

[25] IEEE 2030.5, also known as SEP 2.0, enables communication for SAE standard-compliant EVSE, and defines the framework that enables secure interactions between utility servers and clients, helping to assist with grid stability. As of yet guidelines for implementation of the standard has not been adopted in CA for use in EVSE communication with utility servers and implementation vendors. For example, if a market actor wants to run a V2H program in a CA IOU service territory, program administrators (CAISO DERP, CPUC DRAM, etc.) have not publicly posted (e.g. on program webpages) that their preferred protocol for EV communication is IEEE 2030.5/SEP 2.0.

[26] Rule 21 in this use case is relevant to the off-board DC EV inverter and/or the solar PV inverter. Rule 21 does not apply to a diesel generator operating alone.

[27] Nissan Leaf-to-Home system that must be modified with additional components to handle multiple DER communication and transfer switch capability between the Main and Critical Panels for islanding functionality.

[28] Nissan Leaf-to-Home system as-is.

Labview software. The V2H system utilized the EV's Controller Area Network, or CAN bus, protocol (commonly used in electric vehicle applications to communicate between control and battery resources) to monitor vehicle State of Charge (SOC).

EPIC 2.03b V2H Installation, Functionality, and Costs

Installation & Functionality. For stakeholders interested in deeper details on the key components of the EPIC 2.03b V2H system, the following subsection lists each component's characteristics along with details on its functionality with other system components.

Table 4. EPIC 2.03b V2H System Components

Utility Service and Outage Simulation
• Primary utility service was a 240-volt split single. • Primary island contactor was installed upstream of the residential meter to simulate utility outages.
Main Panel
• Residential 200 amp meter main load center acting as the residential "Main Panel". • Residential Main Panel had several two pole breakers. • Breakers supported: Level 2 electric vehicle supply equipment (EVSE); 5 kW residential storage battery with inverter; and 4.5 kW 240-volt variable resistive load bank that simulated residential loads. • In series with the residential Main Panel was a secondary island contactor.
Critical Panel
• Downstream of the island contactor was a secondary load center referred to as the "Critical Panel". • Island contactor was used to simulate residential island conditions on the Critical Panel. • Critical Panel also had several two pole breakers. • Breakers supported: AC output of the residential storage battery, a Critical Panel level 2 EVSE, a 5 kW solar photovoltaic inverter and a secondary 4.5 kW 240-volt variable resistive load bank used to simulate residential critical loads.
Residential Storage Battery
• 8.6 kWh lithium ion battery. • Inverter rated at 5 kW. • Configured to source energy from the battery to the Main or Critical Panel in increments of 0 – 20 amps. • Charged either from the utility, the solar photovoltaic system or from the V2H system. • Internal transfer switch that allowed Critical Panel to be isolated from the Main Panel in the event of utility service loss. The transfer switch performed a "synch" or "qualifying" procedure prior to closing in the Main to Critical Panel. Communication occured via cellular modem.
Electric Vehicle Supply Equipment
• Configured to connect to either the Main or Critical Panel. • Custom built to allow bi-directional power flow. • An external analog input was used to vary the EVSE duty cycle. • Variable duty cycle would adjust the EVSE current output. Although this feature was not used for the EPIC 2.03b tests, it could have limited the electric vehicle current draw based on sourced energy from the solar photovoltaic system.
Solar Photovoltaic (PV) System
• Inverter rated at 5 kW. • Inverter configured to be sourced by either a 4.5 kW DC power supply or a 6 kW solar photovoltaic system. • Inverter was connected to the Critical Panel.
Load Banks
• Two fully programmable, variable 4.5 kW 240-volt resistive load banks. • Multiple power or current loads entered to simulate steady-state or variable residential loads.

PG&E's ATS group chose these components based on the following criteria:

- Availability for procurement within project timeframe;
- Existing technology in the marketplace;
- Easily reconfigurable for testing purposes;
- Vendor support during testing;
- Local supplier availability;
- Product familiarity by technicians completing tests; and
- Affordability.

Costs. For stakeholders interested in the functionality gained for the homeowner by the EPIC 2.03b V2H system installation, and the associated costs, Table 5 summarizes the key items included in the baseline and test case scenarios of EPIC 2.03b's cost-benefit analysis. Note that the objective of the cost-benefit analysis to compare multiple technologies, necessitated the use of equipment and installation costs listed in Table 5 that were incremental to a hypothetical EV customer baseline home. In particular, the solar PV, EV, and critical panel were assumed to be provided by the customer. This approach allowed the analysis to directly compare the costs and benefits of a hypothesized bi-directional charger with a stationary battery storage device. Conversely, to achieve the customer survey's objective of capturing respondents' willingness to pay for V2H functionality, installing a full V2H system would result in a total cost of approximately $4,500[29] for all components and installation. This figure combines the critical panel costs from the EV customer baseline home, with the incremental hypothesized bi-directional Level 2 charger used in the cost-benefit analysis, to provide a value that was appropriate for capturing respondents' willingness to pay in the survey.

[29] The cost estimate used in the customer survey for a V2H system includes a hypothesized bi-directional charger and installation cost of $2,400 (Table 10) *plus* estimated critical panel costs (transfer switch, panel equipment, switch box) and installation of $2,100. Critical panel costs were not included in the cost benefit analysis because it is common to both Stationary Storage and EV technologies if they are to provide grid islanding functionality. Critical panel costs are hypothesized based on anecdotal market-based quotes obtained by the project for the purposes of the customer survey. There is a high degree of uncertainty in the estimate due to the lack of a commercially available bi-directional charger, and therefore, a lack of procurement and installation experience by the supply chain for a full V2H system. The figures used are intended to provide directional results until the technology achieves commercialization in the California market, and better data become available for further analysis.

Table 5. V2H System Component Cost Snapshot

Component	Baseline Functionality	Test Case Functionality	Cost
Level 2 Charger (baseline)	Vehicle charging only	Replaced with simulated bi-directional unit	Customer-provided
Electric Vehicle	Customer load shifting	Islanded home load service (demand response / outage)	Customer-provided
Solar PV	EV and SS battery recharging through islanded PV generation		Customer-provided
Inverter			Customer-provided
Critical Panel	Second panel for critical loads	Isolated V2H system from grid service	Customer-provided
Stationary Storage (SEP 2.0-capable)	N/A	Controlled islanded home load service (demand response / outage)	Equipment: $6,200 Installation: $2,000
Bidirectional Level 2 Charger (SEP 2.0-capable)	N/A	Simulated charger allowing a controlled bi-directional vehicle charging and discharging to serve islanded home load (demand response / outage)	Equipment: $900* Installation: $1,500 **Assumption based on future state where cost of bi-directional charger is the current cost of leading home chargers and can support higher amperage loads versus current commercially available products.*

3. How viable and valuable is V2H?

V2H Technical Viability

Challenges for V2H systems are centered on the interconnection to an electric vehicle. If the vehicle incorporates an external DC port, interconnection to an inverter is similar to many solutions for distributed energy resources in the market today. Whether selection is for V2H or V2G, the interconnection shares characteristics no different than installing a PV system, less the actual PV panels, because an inverter does not technically distinguish between sources of energy. Considering PV, stationary storage, or in this case an EV's traction battery, the inverter will perform as designed. V2H requires inverter parameters to be based on the EV's traction battery.

Once installed with a capable inverter, an EV can be used to assist with support for household loads – for demand response or grid support – either reducing utility overall demand, or by pushing power back through the PCC, respectively. If a V2H inverter is used (voltage source inverter vs. current source inverter), the EV can act as the primary source of power in the event of an outage, or an intentional utility service disconnect.

V2H Value Streams (see also Section 4.4)

In service of the EPIC Program Charter, PG&E's EPIC 2.03b sought to demonstrate new and novel V2H technology applications and estimate ratepayer benefits associated with these applications.

Addressing the net new V2H testing questions was key to the testing and analysis carried out during this project.

A key net new finding from the project was that test results demonstrate an EV-only V2H system can provide islanding and DR functionality within the scope of the capabilities of the inverter used (*i.e.*, current or voltage source inverter). A second key net new finding was that an EV-only V2H system can provide greater net benefits to the customer and utility than stationary storage, though not cost-effectively for the customer. The system is only cost-effective from a program administrator perspective if the customer bears the equipment capital costs. Another net new finding from the project was that a V2H system with solar PV and stationary storage could provide significant, compounded resiliency benefits in the case of sustained outages. Notably, this resiliency benefit will need to be balanced with mobility needs. Also, it is not clear whether the additional resiliency hours for the site owner translate into value for the utility or society.

Ultimately, the project found that the value of V2H varies significantly depending on the stakeholder viewpoint. The primary driver of the net benefits is the allocation of equipment capital costs among stakeholders. Several key secondary drivers may lead to cost-effective potential future scenarios for the customer such as declining overall technology costs and monetizing additional storage value streams (*e.g.*, customer-driven load shifting, V2G system configuration, and ancillary services support for a utility). In the future, declining costs of the enabling technology and the potential for additional value streams could render a cost-effective result from the participant's perspective. Future analysis should consider the O&M and battery lifetime costs of enabling these value streams.

4. What will it take to make V2H commercially available?

Commercializing the V2H Value Proposition (see also Section 4.5)

Once the technical components for V2H are commercially available, the value proposition of V2H will hinge on an update to Rule 21 that allows connection of such a system. Once the update is complete, V2H commercialization will further rely on development of a communication protocol that allows safe and proper control of the EV systems. Realizing the commercial value of V2H requires conversion of vehicle-grid integration (VGI) demonstrations and pilots into tangible and fruitful business models for energy services, DR, and grid ancillary services in support of V2G. Key barriers to V2H commercialization (Table 2 - identified by the project's research and market stakeholder interview activities) include unclear vehicle regulation, capital costs, limited value capture, standards implementation, and V2H arriving second to market behind stationary storage. These barriers are discussed further in Task 5: V2H Commercial Value Proposition.

Partnerships among automakers, energy aggregators, charging networks, utilities, and mobility providers are needed, though they currently play a mix of complementary and competing roles. The path forward will pivot on the relevance and quality of data from demonstrations in support of the technologies, challenges and insights into this unfolding intersection of the regional electricity and global transportation industries. Ultimately, illuminating these partnership opportunities and implementing aligned market entry strategies to aggregate resources at scale is critical to unlocking and capturing V2H and V2G value streams.

4 Project Activities, Results, and Findings

This section covers the key program activities conducted as part of this investigation, then provides a summary of the results and findings from each activity. This project started with a market and regulatory assessment to provide context and background on the market's current situation.

4.1 Task 1: Market and Regulatory Assessment

EVs have made significant market advances, and sales are projected to continue increasing in the United States and globally. Decreasing battery costs, increasing battery capacity, purchase incentives, local market regulations, and the introduction of long-range vehicles are all factors driving the market for EV adoption in the United States. The potential for these vehicles to provide a benefit to owners and the grid at large by providing power back to the grid or powering a home in an outage situation could make them more appealing to customers. Stationary storage can provide many of the same functions, albeit with a reduced capacity battery (vs. a vehicle), while offering higher availability than a vehicle in a similar role. Therefore, V2H technology will have to compete within a broader, established market of Distributed Energy Resource (DER) technologies.

Stationary storage is a commercialized product in the US market, but no commercialized V2G/V2H products exist to date. There are no products available for V2G or V2H, exhibiting a need for further testing and demonstrations. For this reason, stationary storage systems are not discussed in the same amount of detail as V2G in this section. The following subsections provide the findings from a literature review of the current market and the history of the ability for vehicles in localized power support programs and demonstrations.

4.1.1 Vehicle-to-Grid Beginnings and Background

VGI technologies are designed to utilize EVs as a grid asset. The term VGI refers to a suite of hardware and software technologies that enable EVs to participate in grid services. EVs can provide services to the grid by changing the rate at which they consume power, known as vehicle-to-grid communications for charge management (V1G), or by providing power back to the grid (power transfer), known as vehicle-to-grid (V2G). When V2G functionality is enabled only behind the meter in an islanded mode it is referred to as V2H or V2B. Currently, not all chargers and EVs are equipped with the necessary technology such as communication equipment, appropriate connector options, and controlling software to participate in grid services; those that are, vary in their capabilities due to the immature status of current solution offerings.

Stakeholder Viewpoint: Challenges to Implementing V2X Market

*"…it's not so much the protocol piece, it's that we **need a market to make it valuable**. And if you make it valuable, we will figure out what the right protocols for communicating this stuff is. But you are putting the cart before the horse if you start obsessing about the communication protocol. Create the value, create the market and the industry will figure out how to tap it. Right now, it's just not clear how you get to that value." –Non-profit environmental advocacy group*

*"…the reality is the market, for the first time in a while, is rapidly changing. There's a **fear** on one end that this **'business as usual'** is **beginning to change**."–EMS technology developer*

*Customer survey results suggest **capital cost is a significant business model challenge** as a majority of respondents (54%) were very interested in the V2H technology concept; however, this interest fell to just 9% when estimated cost was revealed. –PG&E EV to Home Concept Test Customer Survey Finding*

Lab research into V2G technology was pioneered in 2007 at the University of Delaware (UD) by Willett Kempton, who began developing the technology in 1996.[30] Prior to lab testing in 2007, several short V2G tests took place across the country and contributed information to UD's project. One of these tests took place in California in 2002 when AC Propulsion completed a 227-hour test of a converted Volkswagen Beetle with a bi-directional grid power interface to study V2G usage. Additionally, UD developed an aggregator function to act as an intermediary between the vehicle and a grid operator.[31] Similarly, in 2006, the Mid-Atlantic Grid Interactive Car Consortium tested V2G capabilities with a Scion xB eBox, for several hours. The information collected from the study included the battery SOC, plug capacity, battery voltage, line current, and regulation signals.[32] These short demonstrations aimed to prove that using inverters and aggregation technology for V2G was possible, and that vehicles could provide electricity back to the grid. Information from these tests was provided to UD and helped to eventually create an onboard, bi-directional inverter which helped further the development of technologies that integrate pieces of the V2G system, such the systems aggregation software that Nuvve purchased from University of Delaware.

Since the onset of V2G research, over 25 V2G pilot projects have taken place spanning three continents, with total funding over $160 million.[33] Kempton piloted the concept of the vehicle as a power storage technology by partnering with NRG Energy to launch eV2g, which began the Grid on Wheels project in 2013.

[30] Karen B. Roberts, "V2G Goes West," *University of Delaware,* July 17, 2017, http://www.udel.edu/udaily/2017/july/vehicle-to-grid-technology-california/.

[31] Alec N. Brooks, "Vehicle-to-Grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle," *AC Propulsion, Inc.,* 2 Dec 2002, https://www.arb.ca.gov/research/apr/past/01-313.pdf.

[32] Adrene Briones et al., "Vehicle-to-Grid (V2G) Power Flow Regulations and Building Codes Review by the AVTA," *Idaho National Laboratory.* Sept 2012, https://energy.gov/sites/prod/files/2014/02/f8/v2g_power_flow_rpt.pdf.

[33] The total funding was calculated using sources for the Vehicle-to-Grid Demonstrations and Pilots, in Section 4.1.3.3 .

NRG's EVgo, licensed through eV2g, has allowed UD's technology to be tested in California through a partnership with the University of California, San Diego (UCSD).[34] In the United States, most VGI pilot projects take place in California given the state's progressive regulatory structure that has encouraged investigating options for battery containing vehicles and the state's ZEV Action Plan which is driving sales of battery containing vehicles. However, an expansion to the East Coast is occurring slowly. Internationally, UD's technology license was sold to Nuvve, a Danish software technology company, in 2011 and was used to create Denmark's first commercialized V2G hub in 2016 via the Parker Project. Nuvve has also utilized the technology in the Nikola Project, and in 2017 announced a partnership with UCSD to implement a pilot program in the United States.[35]

Stakeholder Interviews

Technologies associated with integrating EVs with the grid (discussed in subsequent sections) are developing and advancing in the market; however, various counter arguments may challenge V2H implementation. These arguments, presented in the Electric Power Research Institute's (EPRI's) *Vehicle to Grid State of the Market* 2016 report, demonstrate hurdles stakeholders could face when deciding whether to implement V2G technologies.

PG&E investigated these hurdles by identifying and interviewing stakeholders in the V2H ecosystem. Among the numerous potential stakeholders involved in a V2H implementation, PG&E identified and engaged the following groups for interviews:

- EVSE and smart grid software providers
- EVSE and charging services providers
- Energy Management System technology developers
- Software developers
- Automakers (OEM)
- Non-profit environmental advocacy groups

Each stakeholder has a different perspective on the market and will make decisions based on that perspective. The various stakeholder perspectives collected during the interviews appear in the most relevant sections of this report to add a practical, market-derived dimension to the discussed topics.

For example, OEMs face technical and market challenges to vehicle integration. Until regulatory and legal constraints diminish (or at a minimum, there are consistent policies within nations) or more utilities test V2G technology, some OEMs may be unwilling to produce EVs with bi-directional capabilities due to inability to cover the costs of the enabling technology.

When asked about overall impressions of vehicle-to-X (V2X), stakeholder opinions generally leaned towards a "wait and see" approach due to costs and lack of market demand for the solution.

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[34] Karen B. Roberts, "V2G Goes West," *University of Delaware,* July 17, 2017, http://www.udel.edu/udaily/2017/july/vehicle-to-grid-technology-california/.

[35] Laura Margoni, "Nuvve and UC San Diego to Demonstrate Vehicle-to-Grid Technology Through Energy Commission Grant," *UC San Diego News Center*, 14 June 2017, http://ucsdnews.ucsd.edu/pressrelease/nuvve_and_uc_san_diego_to_demonstrate_vehicle_to_grid_technology.

Customers surveyed indicated an interest in V2H functionality over V2G, suggesting this approach is prudent.

Stakeholder Viewpoint: Opinions and Impressions of V2X and V2H

*Customer survey respondents viewed the technology **primarily as an emergency preparedness tool** and/or a way to retain power during an outage, rather than a mechanism for saving money on their bills, or earning incentives through a program. –PG&E EV to Home Concept Test Customer Survey Finding*

*"**With consent of vehicle OEMs,** we would support such usage, but have not yet been requested by customers for such functionality. Additionally, safety, permitting, and cost issues associated with necessary additional power conversion equipment would also need to be overcome for such a solution to become economically viable at scale. Efficiency of V2X utilization will be **best in DC-to-DC scenarios and high voltage,** perhaps less likely to take broad scale form in the residential setting." – EVSE and smart grid software provider*

*"We're **trying to figure out if the business model itself is financially sustainable** in the long run… [we are] highly focused on public fast charging, and it's really not a good fit to do VGI, V2G, because you want to get people in and out and always be available for a full charge when they need it." –EVSE and charging services provider*

*"…fully believe**, from a technology standpoint, that this is the way we're going**, it's rather a question of how long before this can make an impact on the grid. That's where there are differing schools of thought. The technology is already there, it's a matter of deploying to the market." –EMS technology developer*

Despite the arguments against implementing the technology, pilot projects are taking place in several countries. The current arguments in favor of V2G resonating throughout the market value chain, as documented in the project interviews, are likely to continue motivating stakeholders involved in the pilots to pursue advancements in V2G technology testing.

4.1.2 Customer Survey

The project conducted a concept test survey of PG&E's Customer Voice panel to better understand consumer interest in V2H technology and assess the current market potential for such a product. The survey request was sent via email to residential customers who have opted to participate in periodic surveying from PG&E. Questioning was conducted online and overall there were 2,486 respondents to the survey, with 441 of those owning an EV. The survey design was a concept test. Due to the short and high-level qualities of a concept test the results are not a conclusive pricing analysis or guarantee of potential adoption; however, the results do produce directional signals about customer interest and willingness to pay for V2H and V2G capabilities.

The survey first presented the EV owner population with the V2H concept absent of price and determined that over half (54%) were very interested in the general technology. The survey then asked a series of questions to determine customer willingness to pay and optimal price level to attract interest from at least 50% of the EV owning customers. The project estimates the optimal price from a customer perspective for a full V2H system to be around $800. Above a $1,000, V2H system cost interest drops dramatically as consumers do not feel that the frequency of power outages justifies the expenditure. When the actual estimated price (about $4,500[36]) was revealed, interest significantly declined to less than 10%. This interest level held roughly constant for both the EV owning and non-EV owning populations, and remained at this low level when incremental V2G functionality and technology costs were introduced.

Respondents viewed the benefits of the technology primarily as an emergency preparedness tool (29%) and/or a way to retain power during an outage (25%), rather than a mechanism to save money on their bills (21%), or to earn incentives by participating in PG&E programs such as demand response (2%). Notably, the first two are functionalities of a V2H system and the second two are functionalities that produce less interruption to a customer when performed with a V2G system. This finding indicates that that business models built to offer V2H functionality are likely to gain early traction over V2G-focused business models. The finding further indicates that V2H benefits will accrue primarily to individuals.

The survey explored the individual benefits of resiliency (using V2H as an emergency preparedness tool) and reliability (way to retain power during an outage) in further detail by asking survey respondents about their experience with, and concern about, outages. While most customers reported experiencing multiple power outages in the last 2 years, they tended to be infrequent and of short duration. As a result, relatively few respondents (only 12%) are very concerned about outages. The same 12% margin of respondents said they would be much more likely to consider purchasing an EV if it was capable of V2H functionality (despite knowledge of the full cost of implementing a V2H system at their home). Thus, there is a potential market opportunity for EV manufacturers to appeal to this group of prospective EV consumers. See Appendix G for the full survey report and results.

Vehicle-to-Grid and Vehicle-to-Home

While V2G and V2H require similar standards, technology, and infrastructure requirements, the two applications for electric vehicles have significant differences. From the customer point of view, V2G is a service with the primary purpose of generating revenue for the vehicle owner. V2H applications are focused on the concept of islanding, or separating from the grid for the purposes of reliability for the customer (*i.e.*, the EV provides electricity in the event of a power outage). While the demonstrations discussed in this report are primarily V2G-based projects, the trends and advances in technology and testing can be applied to V2H projects as well.

[36] Estimated full cost of V2H system (technology and installation, but not the cost of an export capable EV) is higher than the incremental cost value used for the cost benefit analysis as explained in Section 3.4 . The survey tested customer reaction to estimated full system cost, even for customers who already have level 2 charging installed, because V2H implementation will require all new hardware.

4.1.3 Technology, Market, and Generational Testing

As discussed in Section 3.4 , V2G/V2H systems generally require several key technologies and capabilities. Most technologies for V2G pass through a series of phases that allow testing to move from a limited and controlled environment toward uncontrolled real-world settings where they interface with multiple interacting technologies.

For initial tests, the demonstrations have typically been carried out in a lab setting and for shorter periods of time—*e.g.*, AC Propulsion's 2002 test that took place in a lab for 227 hours. The lab setting verifies the ability to safely test a technology and establishes the potential to deploy it in a real-world setting. Once lab testing is completed, the technology is tested in a manner that minimizes systemic interactions, but determines its ability to successfully operate in a controlled environment.

The next step is testing these technologies in conjunction with other technologies to showcase the benefits V2G may have on larger market or grid systems. By using V2G technology in conjunction with others, such as stationary storage or solar PV, V2G can become integrated into larger systems and provide more value to the customer and utility. Since it is expected V2G technologies will be deployed in a market where other technologies like PV already exist, analyzing technological interactions and the outcomes they produce is a critical step ahead of real-world testing. The final stage of testing V2G is deployment in a real-world setting and analyzing how systems and customers interact with the technologies. To date, the Parker Project in Denmark discussed in Section 4.1.3.3 has reached this final phase, with other projects likely approaching real-world deployment as well.

V2G and Automakers

OEMs do not currently sell EVs that are V2G-ready in the United States, although V2G test are underway. For example, V1G is being tested in BMW's iChargeForward pilot with PG&E. This test does not require the additional complexity of providing power back to the grid, as automotive OEMs are generally unwilling to permit discharge from the battery by an outside control due to warranty issues. By only allowing the vehicle's powertrain control system to discharge energy, it ensures battery function is always tied to the number of miles driven. This reduces an OEM's warranty liability, which is currently tied to mileage, thereby limiting V2G deployment until warranty issues are resolved. Additionally, OEMs face the challenge of determining at the point of vehicle purchase whether the owner intends to participate in V2G services.

Two stakeholders interviewed for this study commented on battery warranty issues as they relate to V2X applications. An OEM stakeholder stated that it would be helpful to understand how to modify the vehicle battery warranty to be based on hours of operation rather than miles. An electric vehicle supply equipment (EVSE) and charging services provider stakeholder, who has previous OEM experience, commented that the anticipation that OEMs would void a factory warranty on the battery if it were used for V2X, has limited pilot activities in the US market. A potential solution, in this stakeholder's opinion, is to create a source of funding that covers any potential malfunctions during pilot testing.

> *"**[The technical] dilemma is about the warranty on the battery**. It's being ignored by the automakers at the moment…The warranty is done by law and would somehow have to be changed, maybe changed to by hours driven. They're worried about the discharges of a vehicle, it may restrict the amount of charge that could be pushed back into a grid."*– Software developer

Some support for V2G from automakers exists internationally, with current market leaders focusing on CHAdeMO DC plug connectors. DC connectors have communication with the vehicle built into their standards and communication is needed to control the flow of power offboard. Mitsubishi and Nissan are embracing CHAdeMO as their preferred DC plug because it is the standard in their home market of Japan. However, for US and European automakers, the SAE combo plug is the standard being used for DC charging.

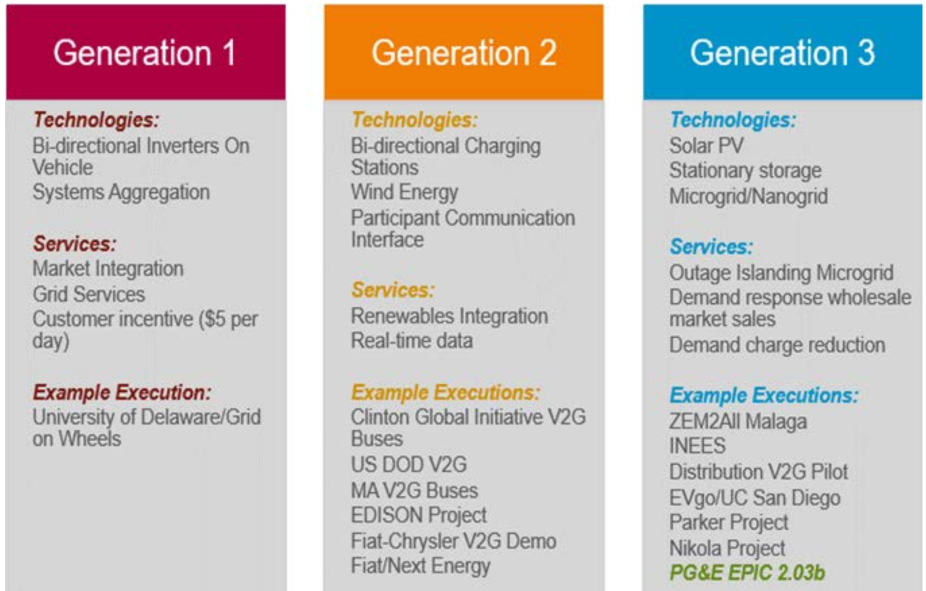
Some OEMs have partnered to create fleet aggregation solutions. Honda, BMW, Chrysler, Ford, General Motors, Mercedes-Benz, Mitsubishi, and Toyota are involved in testing communication between utilities and a central server to control charging plug-in EVs (PEVs). The Open Vehicle Grid Integration Platform was designed to prove the value of a common platform between utilities and PEVs.

4.1.3.1 Generational V2G Technology

Based on market trends, the V2G demonstrations were grouped into three generations based on the technologies used in coordination with V2G. As some demonstrations utilized the newest technologies available in the market while others did not, newer demonstrations are not necessarily using the latest technology. The generations, depicted in Figure 6, become increasingly more complex due to more components which have interactions that need managing. This increasing complexity proves V2G's ability to progress through testing phases and integrate more technologies and, create more value by opening new value streams for commercialization of V2G.

- **Generation 1:** The first generation is a product of UD and Kempton's developments and includes bi-directional inverters on an EV, systems aggregation, grid services, and market integration. The first generation laid the foundation for future R&D on V2G.
- **Generation 2:** The second-generation advanced bi-directional technology to the charging station. Renewables became integrated into testing, and participant communication interfaces were used. Second generation renewable usage was limited to wind energy.
- **Generation 3:** The number of technologies used with a V2G implementation grew in 2012 to evolve into the third generation. Solar PV, stationary storage, microgrids (islanding microgrids), value-added services, and local DER mix integration are considered third generation technologies and services.

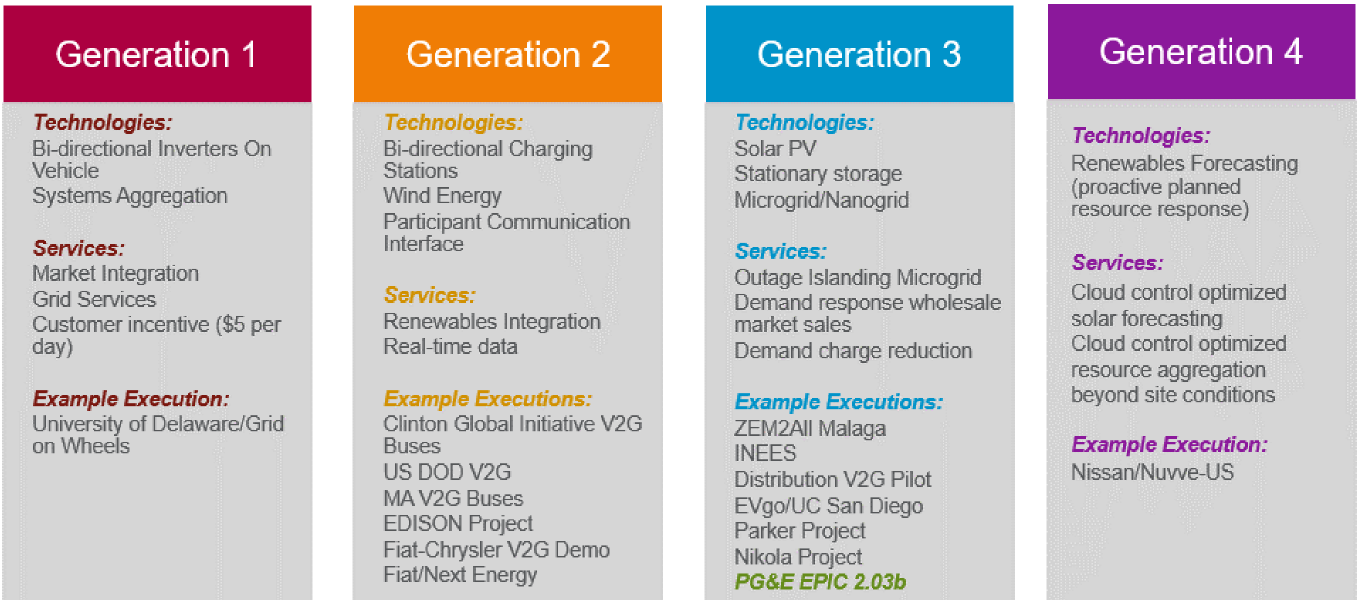
Figure 6. V2G Technologies, Services, and Demonstrations: Past and Present Generations



These generations show V2G development and implementation evolving with increasing functionality and complexity. PG&E's 2.03b pilot applies a Generation 3 level of complexity—with stationary storage, solar PV, and bi-directional power flow—to V2H functionality. See other Generation 3 V2G demonstrations, such as ZEM2All Malaga summarized in Section 4.1.3.3 .

The development of the previous three generations of technology and services were used to anticipate the arrival of a fourth V2G generation. The fourth generation, depicted in Figure 7, starts to change the paradigm from a reactive response to a grid signal to a proactive, planned response based on renewables forecasting. An example of integrating renewables forecasting is the use of solar forecasting, which the Nissan/Nuvve-US demonstration at UCSD has announced it will use. By predicting when high amounts of sunlight could be received by solar panels in a given area, grid operators could signal to EV owners to charge their vehicles, if the grid has integrated renewables. Wind energy forecasting has not been announced in any upcoming V2G projects, but it could be integrated in a similar fashion as solar forecasting.

Figure 7. V2G Technologies, Services, and Demonstrations: Future Generation



While earlier generations did perform some onsite and local optimizations, optimizing systems via cloud services is predicted to be a key component of the fourth generation, as depicted in Figure 8. The Nissan/Nuvve-US project will use both local and cloud-based approaches to its solar forecasting. By integrating a cloud control and optimization element, service providers can tune the available resources to a greater degree and optimize them by aggregating and tuning load across many systems simultaneously, while helping avoid the unintended consequences of only optimizing a system to its site conditions.

Figure 8. Cross-Generational V2G Technologies and Services

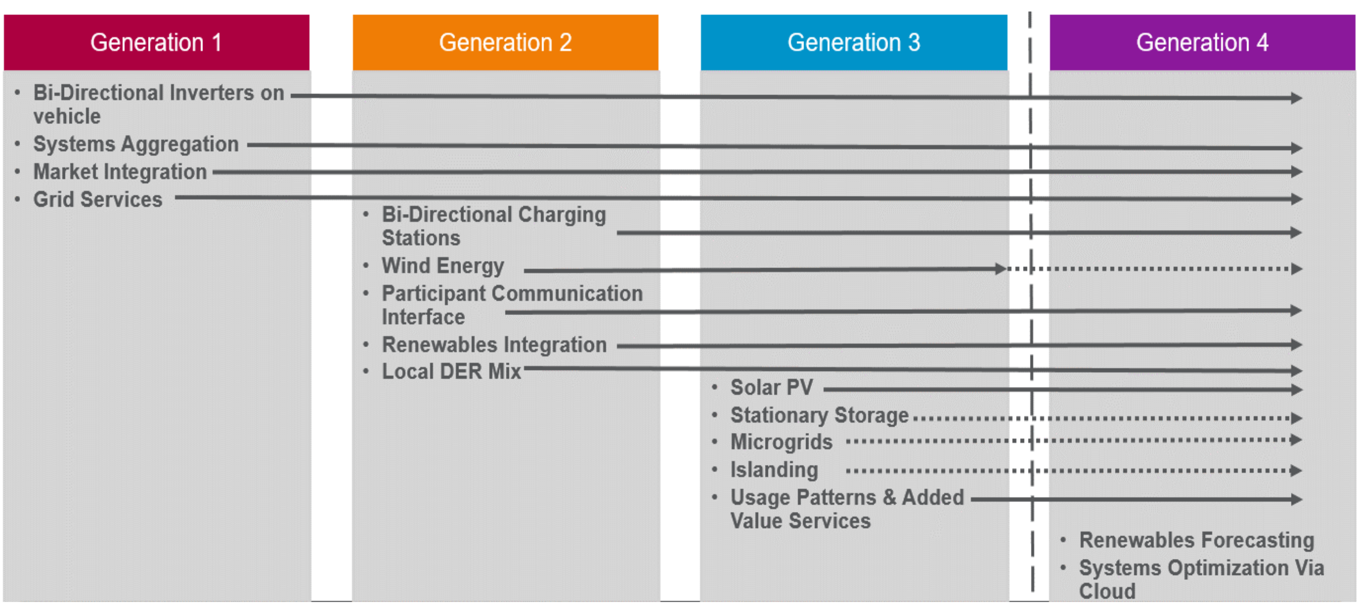


Figure 8 illustrates that incorporating new technologies in V2G demonstrations does not necessarily mean the elimination of others; rather, it reflects evolutionary additions. For example, bi-directional inverters, bi-directional charging stations, power flow control platforms, and stationary storage are all still used with Generation 3 technologies, despite being considered part of previous generations. These evolutionary advances allow the study of interactions that each newly added device introduces to the V2G system. Some demonstrations themselves have evolved—such as the US Department of Defense (DOD) V2G Demo—having incorporated new technologies as the project progressed.

Most technologies have completed rounds of lab tests (Generations 1 and 2), and the evolution of controlled environment tests (Generations 2 and 3) has aggregated an increasing number of these technologies together to better understand potential interaction effects. The longer-running demonstrations have incorporated the primary technology evolutions and have begun to include elements of customer feedback and systems integration. PG&E expects this trend will continue with more technology deployed outside of controlled environment testing in real-world uncontrolled environments (Generation 4). These emerging real-world demonstrations will initially remain confined to specific geographies and enrollment targets, while confirmation analysis on hardware, software, system interactions, and customer feedback takes place. This evolutionary process could lead to commercial rollouts of these technologies and systems in locales where V2G grid services can generate sufficient benefits, and stakeholders can develop business models capable of monetizing those benefits.

4.1.3.2 V2G Technology Trends

The evolution of technologies used in V2G beginning in 2007 through the present, showcases two dominant trends. First, partnerships are a dominant trend among all discussed demonstrations. Several demonstrations in the United Stated and Europe have used the technology developed at UD, and partnerships have allowed that technology to be advanced by other stakeholders. This is to say that technologies are building off one another. Building on previous work has proven critical for the advancement of V2G technologies due to their evolutionary nature.

The second trend that emerged is generational improvement driven by evolutionary additions. Implementing a new technology in a demonstration does not call for another technology to be completely phased out; and because of increasing complexity among technologies, this will likely continue. The future of V2G will likely include a host of technologies depending on stakeholders' research goals or the needs of customers.

These trends indicate potential for continued testing and eventual launch into the market for V2G technologies; however, some barriers stand in the way of full commercialization. Standardizing key components, communication protocols across market participants, and methods for participation in a potential V2G market are required precursors before this technology will be ready for a real-world market launch. Solutions to these barriers are offered in Section 4.5.1 .

4.1.3.3 V2G Demonstrations and Pilots Summaries

1. **Grid on Wheels:** As a pioneer in the field of V2G, UD began testing its bi-directional inverter technologies in 2007, with a pilot beginning in 2012, known as Grid on Wheels.[37] The project aimed to demonstrate the university's vehicle aggregation software, which is capable of electronically combining many different vehicles' batteries in different locations and presenting

[37] "Vehicle to Grid Demonstration: Project Overview," *Grid on Wheels*, http://grid-on-wheels.com/.

them as a standalone single energy storage plant.[38] The project took place in a lab and commercial/fleet settings and incorporated market integration, grid services, usage patterns and value-added services, and participant feedback/communication. The project proved that vehicles can provide services back to the grid, and on average, earned $5 per day from ancillary service market participation in PJM territory.[39]

UD's V2G technology is currently being used in Denmark through Nuvve under different project names, including the Parker Project. The university V2G team, led by William Kempton, continues to test and develop V2G technology that is used in several projects and demonstrations in the United States. The Grid on Wheels project is currently complete but will be re-vamping in 2018.

2. **EDISON Project:** Based in Denmark, EDISON (EVs in a Distributed and Integrated market using Sustainable energy and Open Networks) was a 4-year demonstration and development project beginning in 2009. The objective of the project was to prepare and provide a technical platform for Danish V2G demos and develop standard system solutions for EVs. The testing took place in lab and commercial/fleet settings, and included renewables integration, market integration, grid services, local DER mix, usage patterns and value-added services, and participant feedback/communication.[40]

   Wind power, abundant in Denmark, was used to charge EVs in the project's test fleet. The project used mapping and traffic patterns to match vehicles needing a charge to grid resources. The batteries in the EVs were used as distributed storage for the wind power. EDISON found that EVs were parked 90% of the time and that a fleet would be able to participate in ancillary service markets. While a short demo of V2G capabilities was completed, the project focused on V1G testing, and data collected was used to predict impacts of V2G on the Danish grid.

3. **Fiat-Chrysler V2G:** From 2009 to 2014, Fiat-Chrysler and the US Department of Energy ran a demonstration with 140 PHEV up-fitted Dodge Ram 1500 pickup trucks, funded by the American Recovery and Reinvestment Act.[41] A portion of the trucks had bi-directional capabilities and were tested in a commercial/fleet setting. The trucks were driven in diverse geographies and climates to test usage patterns, verify charging mode performance, and develop a bi-directional charger interface. The project included participation from seven utilities that found it easier to implement V2H rather than V2G.[42]

4. **INEES:** The intelligent integration of EVs into the power grid for the provision of system services (INEES) project was conducted in Germany using V2G-modified Volkswagen e-up!s and bi-directional DC chargers. The project's objective was to investigate the possibility of balancing and stabilizing the power grid using EVs.[43] The testing took place in a residential setting and

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[38] Karen B. Roberts, "Vehicle-to-Grid," *University of Delaware,* 29 August 2016, http://www.udel.edu/udaily/2016/august/vehicle-to-grid-denmark/.
[39] Navigant Research, "Vehicle Grid Integration," *Navigant Consulting Inc.,* 2015.
[40] Carl Binding et al., "Electric Vehicle Fleet Integration in the Danish EDISON Project—A Virtual Power Plant on the Island of Bornholm," *EDISON*, www.edison-net.dk/~/media/EDISON/Papers/EVPP.ashx.
[41] Navigant Research, "Vehicle Grid Integration," *Navigant Consulting Inc.,* 2015.
[42] Information received from stakeholder interview conducted by the PG&E project team.
[43] Mark Kane, "INEES Project: V2G Reduces Power Fluctuations, but is not Economically Viable," *InsideEVs*, 2016, https://insideevs.com/inees-project-v2g-reduces-power-fluctuations-but-is-not-economically-viable/.

incorporated grid services, usage patterns and value-added services, and participant feedback/communication.

The project allowed participants to drive the fleet EVs for 1 year and tracked driving behavior through a mobile phone app. Participants were incentivized to partake in the program through monetary rewards for charging, which covered the cost of charging electricity and were funded by the German government. The results of the project concluded V2G is a feasible way to provide capacity to the grid, but it was not economically viable at the time of the project. INEES noted that legislative changes and technology advancements could improve the economic viability of a V2G program in Germany.[44]

5. **ZEM2All Malaga:** The Zero Emission Mobility to All project deployed a fleet of 200 EVs and 243 charging points (both Level 2 and fast charging) in Malaga, Spain beginning in 2012. It aimed to provide citizens with access to electric mobility and included renewables integration, market integration, grid services, local DER mix, islanding microgrids, usage patterns and value-added services, and participant feedback/communication.[45]

   The program used bi-directional charging stations to contribute power back to the grid, in addition to microgrids with solar PV and stationary storage. Participants utilized the vehicles throughout the demonstration. The program found at the conclusion of the project in 2016 that participants were satisfied with the program and likely to keep the vehicles. The program showed a need for large-scale deployment of EVs in other Spanish cities.[46]

6. **Fiat-Chrysler/NextEnergy:** Fiat-Chrysler partnered with Detroit-based NextEnergy in 2013, testing four Town and Country minivans with all-electric V2G powertrains to see how reverse power flow affects independent system operator (ISO)-operated grids in a lab setting. In addition, the project tested the economic viability of V2G business models. The minivans were connected to a charging station that simulated different grid situations, including balancing assets from renewables.[47] The project identified that using inverters on vehicles may be more efficient for V2H, and it may be better from a cost perspective to use offboard inverters (charging stations) for V2G.[48] The project evolved into testing Fiat 500e vehicles in V2H and vehicle-to-building configurations.

7. **Nikola Project:** In 2013, this Danish project set out to analyze all services a vehicle could perform on the grid. As a partner, Nuvve used technology from UD in addition to offboard, bi-directional inverters, solar PV, and wind. The testing took place in a lab and commercial/fleet settings, and services included renewables integration, market frequency, grid services, local DER mix, islanding microgrids, usage patterns and value-added services, and participant

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[44] "INEES- Energizing Electric Cars," *LichtBlickBlog,* June 23, 2016, http://www.lichtblickblog.de/en/swarmenergy/inees-energizing-electric-cars/.
[45] "ZEM2ALL Spain's Largest Electric Mobility Project Ends After Four Years," *Energy News,* February 12, 2016, https://www.energynews.es/english/zem2all-spains-largest-electric-mobility-project-ends-after-four-years/.
[46] "ZEM2ALL Travels 4.6 Million Kilometers and Prevents the Emission of 330 Tn CO2 into the Atmosphere," *Endesa,* January 29, 2016, https://www.endesa.com/en/press/news/d201601-zem2all-travels-46-million-kilometers-and-prevents-the-emission-of-330-tn-co2-into-the-atmosphere.html.
[47] Navigant Research, "Vehicle Grid Integration," *Navigant Consulting Inc.,* 2015.
[48] Information received from stakeholder interview conducted by the PG&E project team.

feedback/communication. The project, which used a fleet of Citroen C1s, ended in 2016 and found that vehicles have the capability of providing many services to the grid and can integrate multiple outside sources. The findings from the Nikola Project were used to implement the Parker Project.[49]

8. **The Parker Project:** Using the bi-directional inverters and platform from UD, Nuvve started the first fully commercialized V2G fleet in Denmark in 2016. The Parker Project builds off the Nikola and EDISON projects and incorporates market integration, grid services, usage patterns and value-added services, and participant feedback/communication. The project's objective is to apply grid-balancing services to a fleet of EVs to demonstrate their potential to support the electricity grid as power resources.[50] Nuvve partnered with Nissan to use the automaker's e-NV200 vans for fleet testing in the project that began in 2016—the vehicles will also be used in the Nissan & Enel V2G demonstration in the United Kingdom, which was announced in 2016.

9. **Clinton Global Initiative School Bus Demo:** In 2013, the school bus demo was proposed and funding was secured in 2014 to begin developing and deploying electric school buses. Because school buses are inactive for most the day and have a predictable usage pattern, the objective of the project was to prepare electric buses to contribute to the grid. The buses are V2G-enabled through bi-directional inverters located on the vehicle and include grid services, market integration, usage patterns and value-added services, and participant feedback/communication. One barrier the demo encountered was the need to upgrade utility pole transformers in the school districts chosen to participate, and sees being proactive in upgrading infrastructure to be a valuable lesson learned. The project is ongoing—a next phase will compare field tests between school districts.[51]

10. **US DOD V2G Demonstration:** In 2014, the US DOD announced its V2G demonstration on the Los Angeles Air Force Base (LAAFB) and several partnerships with OEMs. The project aims to prove that EVs can meet energy directives, explore related benefits of EV technology to include revenue generation, and initiate large-scale integration of EVs into the DOD's non-tactical ground fleet.[52] The project uses a commercial/fleet setting for testing and includes market integration, grid services, local DER mix, and usage patterns and value-added service.

    The LAAFB portion of the program found that the monthly lease price of an EV sedan could be reduced by 72% using frequency regulation while charging in Southern California.[53] Installations on bases in Colorado, Hawaii, New Jersey, and Maryland have begun or are in the planning phases to expand the geographic reach of the testing. The demonstration is ongoing and as a next step, the DOD will implement used batteries as on-base energy storage.

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[49] Peter Bach Andersen et al., "The Nikola Project Intelligent Electric Vehicle Integration," *Technical University Denmark*, 2014, http://orbit.dtu.dk/files/101856208/ISGT2014IstanbulNikola_Final.pdf.
[50] "About Parker," *The Parker Project,* 2016, http://parker-project.com/
[51] "ZEV School Buses- They're Here and Possible Free," (Presentation, November 3, 2016), http://www.green-technology.org/gcschools/images/ZEV_Buses_Possibly_Free.pdf.
[52] Camron Gorguinpour, "DoD Plug-In Electric Vehicle Program: The DOD V2G Pilot Project Overview," (Presentation), http://electricvehicle.ieee.org/files/2013/03/DoD-Plug-In-Electric-Vehicle-Program.pdf.
[53] Navigant Research, "Vehicle Grid Integration," *Navigant Consulting Inc.,* 2015.

11. **EVgo and UCSD:** In 2015, NRG EVgo partnered with UCSD to operate a fleet of nine Nissan and Honda EVs with bi-directional charging capabilities. The objective of the project is to have OEMs and charging networks preparing their vehicles and technologies to move past the demonstration stage into commercialization.[54] Partners on the project include Honda, Nissan, UCSD, Kisensum, UD, and EVgo. The testing is taking place in a commercial/fleet setting and is utilizing renewables and market integration, grid services, local DER mix, usage patterns and value-added services, and participant feedback/communication.

    The project has two parts, the first of which is to examine DC fast charging with solar PV, stationary storage, and provide services to the grid. The charging stations are connected to a microgrid on UCSD's campus, which provides 85% of power supplied to the university. As a second part of the project, a fleet of Nissan and Honda EVs equipped with bi-directional chargers will be leveraged.[55] The project was projected to have a completion date of summer 2018, but no recent updates on the project are available.

12. **Distribution System V2G for Improved Grid Stability for Reliability:** Organized by EPRI and several OEMs, the Distribution V2G project began in 2015 in California. The objective of the project is to address interfacing issues for bi-directional flow between PEVs and the grid, as well as design interfaces for modularity to accommodate the value of current and future grid services. The project is currently testing bi-directional charging stations and solar PV as a V2G asset at UCSD, with an estimated completion date of summer 2017. The testing is taking place in a commercial/fleet setting, and as a next step will release and analyze pilot results. Distribution V2G has active coordination and asset sharing with the UD V2G research and testing program.[56]

13. **Massachusetts V2G Electric School Bus Pilot:** Similar to the Clinton Global Initiative School Bus Project, the MA V2G Bus Pilot aims to be one of the first EV school bus demonstrations on the East Coast, and to analyze the economic viability of electric school buses. The project will include market integration, grid services, local DER mix, islanding microgrids, and customer feedback/participation. In 2015, the project began seeking school districts throughout the state for participation. Although specifics are unknown, the pilot will utilize V2G and vehicle-to-building technologies. Four school districts were chosen in 2016, and the next step for the project is to begin testing.[57]

14. **Nissan/Nuvve – US:** In June 2017, Nuvve announced it would be partnering with UCSD to use 50 bi-directional charging stations on the campus to further test technology used in the Danish V2G projects. The project will utilize renewables and market integration, grid services, local DER mix, usage patterns and value-added services, and participant feedback/communication. The demo has secured funding, and the next steps will be to begin the pilot and involve participants. Solar

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[54] NRG, "Project Background," *NRG,* http://www.energy.ca.gov/research/notices/2015-12-14_workshop/presentations/07__NRG__de_Leon.pdf.
[55] Laura Margoni and Jeremy Desel, "UC San Diego and NRG EVgo Partner to Support Innovations in Electric Vehicle Charging," *UC San Diego News Center*, November 10, 2015, http://ucsdnews.ucsd.edu/pressrelease/uc_san_diego_and_nrg_evgo_partner_to_support_innovations_in_electric_vehicle.
[56] D. Bowermaster, "Vehicle-to-Grid: State of the Technology, Markets, and Related Implementation," *EPRI,* June 2016, https://www.epri.com/#/pages/product/000000003002008935/.
[57] "Electric School Bus Pilot Project Launching in Massachusetts," *Vermont Energy Investment Corporation,* December 1, 2015, https://www.veic.org/media-room/news/2015/12/01/electric-school-bus-pilot-project-launching-in-massachusetts.

forecasting technology will be added to the mix of technologies used in the Danish phase of the Nissan/Nuvve project, which will predict solar output and optimize vehicle charging based on the predictions. The project is expected to last 3 years and aims to remove barriers to V2G implementation in California.[58]

Stakeholder Viewpoint: Most Promising Demonstrations of V2X Capabilities

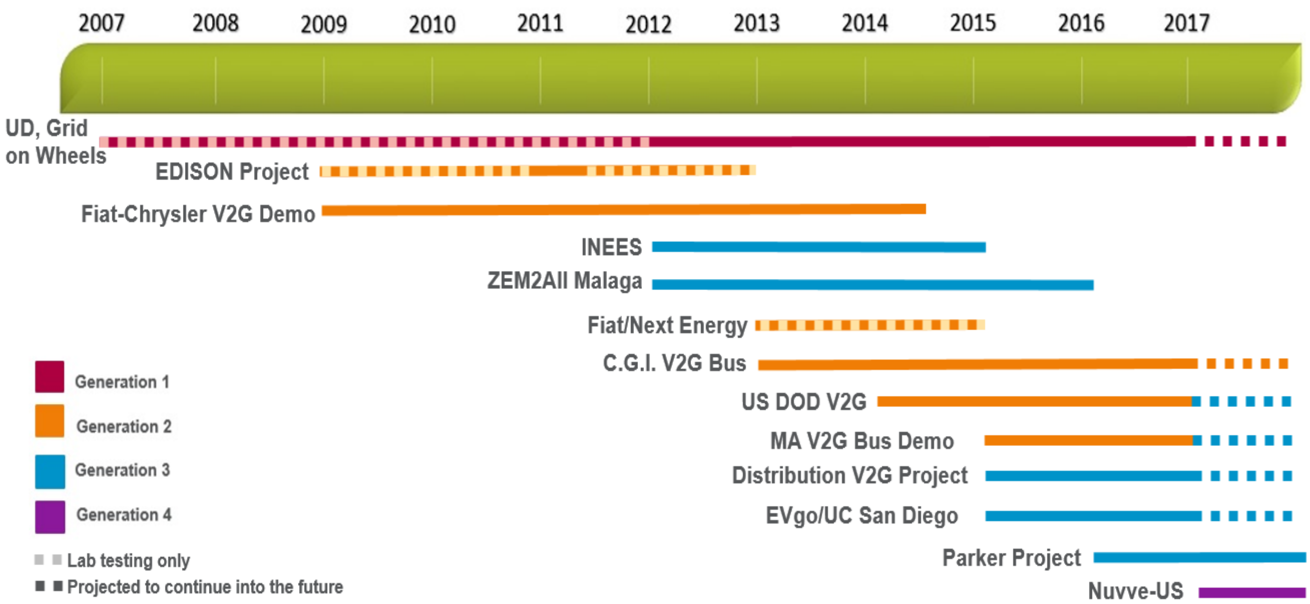
*"Well I guess I would have to point to the **University of Delaware** and some of the work they have done. The DR in…some of the areas are up to 1000 dollars a kW. University of Delaware took some BMWs and Minis and did a program which I think showed that they were making money from the utility. And that is …the most promising application I have seen. They would never talk about how much it cost, they just talk about making money off the utility." –EVSE and charging services provider*

*"…**PG&E's pilot** before the commission now that relates to school buses that – it's not V2G yet – but they've talked about making it [V2G], and how the duty cycle is well suited for it." –Non-profit environmental advocacy group*

Figure 9 characterizes the V2G demonstrations based on the technological generation, discussed previously in this section.

[58] Laura Margoni, "Nuvve and UC San Diego to Demonstrate Vehicle-to-Grid Technology Through Energy Commission Grant," *UC San Diego News Center,* June 14, 2017, http://ucsdnews.ucsd.edu/pressrelease/nuvve_and_uc_san_diego_to_demonstrate_vehicle_to_grid_technology.

Figure 9. Generational V2G Demonstrations Timeline



4.1.3.4 Japanese and International Smart Grid Projects

Smart grid projects taking place across the world also contribute to the generational growth of research insights into V2G and V2H technologies. While these projects are not exclusively testing V2G/V2H, some do incorporate vehicle testing. Japanese automakers Nissan, Mitsubishi, and Toyota have played an active role in expanding V2H in Japan and across Europe. Nissan's LEAF to Home launched in 2012 and supplies a home with energy stored in a LEAF's battery. By the end of 2016, 4,000 Japanese homes were using the product, and Nissan announced plans in 2017 to commercialize the LEAF to Home product in the United States.[59] Mitsubishi sold a similar product, the Power Box, to Japanese customers purchasing the i-MiEV.[60] Denso, a Japanese automotive component manufacturer, and Toyota partnered in 2012 to create a V2H power supply system. As of 2016, the product was still being tested. Toyota also participated in the iZEUS (intelligent zero emission urban system) project in Germany by providing four V2G-capable Prius PHEVs for use in an onboard inverter, bi-directional charging pilot program.

Through these pursuits in V2G and V2H technologies, Japan is a leader in performing V2G/V2H demonstration projects, primarily through smart grid projects. In 2010, two smart grid demonstrations began in Japan with V2H components. The primary focus of the Yokohama City and Toyota City smart grid projects was to test smart grid technology, with vehicles incorporated into their test plans.[61] The learnings from these demonstrations contributed to the evolution of standards and allowed the launch

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[59] Lidia Todorova, "2012 Nissan Leaf Powered by 'LEAF to Home' Power Supply System with 'EV Power Station'," *Automobiles Review,* May 30, 2012, http://www.automobilesreview.com/auto-news/nissan-leaf-powered-home-power-supply-system/48492/.

[60] Keith Barry, "Mitsubishi Turns their EVs into Portable Power Supplies," *Wired*, March 19, 2012, https://www.wired.com/2012/03/mitsubishi-turns-their-evs-into-portable-power-supplies/.

[61] Amy Poh Ai Ling, et al., "The Japanese Smart Grid Initiatives, Investments, and Collaborations," *International Journal of Advanced Computer Science and Applications* 3, no. 7 (2012): 1-11, https://arxiv.org/ftp/arxiv/papers/1208/1208.5394.pdf.

of a retail V2G/V2H product by Nissan promoted as Leaf-to-Home and mentioned above. The success of deploying several demonstrations in Japan could be attributed to only having 10 electric power companies in the country, compared to the more than 3,000 in the United States.[62] Additionally, more than $100 billion was invested in Japan in the 1990s to upgrade generation and transmission, including last mile, infrastructure, demand-side management, and residential distributed solar throughout the country. For comparison, approximately $30 billion was invested into the grid in the 1990s in the United States.

Japanese companies have since begun partnering on projects in Europe, such as Nissan's involvement in the United Kingdom's Enel Smart Grid Project. Nissan and Enel are incorporating V2G technology through a smart grid project, using Nissan LEAFs and Nissan e-NV200 electric vans. The Amsterdam Smart City project, with partnership from Mitsubishi, also has a V2G/V2H component. Residents participating in the pilot will have the option to transfer energy from their vehicles to the grid or store electricity in the vehicle to be used to run household appliances in a V2H fashion.[63] In the United States, the JumpSmartMaui project began in 2013 and incorporated EVs, smart grid, and renewable energy solutions into the Maui grid.[64] Table 6 lists smart grid projects across the globe that are utilizing vehicles as storage or grid assets, providing more testing scenarios that may show potential for commercialization.

Table 6. International Smart Grid Projects

Project Name	Country	Year Started
SmartGridCity Project	United States	2008
Austin Energy V2Green	United States	2008
MeRegio Mobil	Germany	2009
Amsterdam Smart City	Netherlands	2009
Toyota City	Japan	2010
Yokohama City	Japan	2010
SPIDERS	United States	2011
JumpSmartMaui	United States	2013
SCE: Irvine Smart Grid Demonstration	United States	2013
Enel	United Kingdom	2016
Avista	United States	2016

4.1.4 Regulatory Examination

Policy support for VGI in California has been strong. In 2013, the CPUC established a proceeding that addresses issues relating to alternative-fueled vehicles (AFVs) through rulemaking 13-11-007. As of 2016, the scope of the proceeding includes the expansion of the development of VGI resources and

[62] In 2016, however, Japan liberalized their retail power market allowing for new entrants into the market, potentially impacting the viability of V2H in some regions.
[63] "About Amsterdam Smart City," *Amsterdam Smart City,* 2017, https://amsterdamsmartcity.com/network/amsterdam-smart-city
[64] "JUMPSmart Maui," *Hawaii Natural Energy Institute,* 2017, https://www.hnei.hawaii.edu/projects/jumpsmart-maui.

programs.[65] Additionally, SB 350 took effect on January 1, 2016, prompting the CPUC to order the three investor-owned utilities (IOUs) to develop transportation electrification programs. While none of the submitted applications actively include V2G demonstrations, some passively mention the possibility of exploring V2G capabilities in later stages of the pilots.[66] [67] [68]

Policy-driven VGI activity in California has primarily been driven by funding from the California Energy Commission (CEC). Over $25.3 million in funding from multiple sources has been awarded for several EV related projects, including the construction of charging stations and VGI research.[69] The Nuvve project with UCSD (see detail in in Section 4.1.3.3) is funded by a CEC grant through the EPIC program, the same funding source for PG&E EPIC 2.03b.[70]

Stakeholder Viewpoint: Opinion and Impressions of V2X and V2H

*"Even if the technology is there today, **regulatory issues take a long time** to do and automakers won't make production vehicles until it's solved."–Software developer*

*"So here is the problem—**there are a lot of standards that have to be developed**. V to X AC isn't really in play. If we were just closing the contactor on our AC units we could do it tomorrow. So, we have to develop a new DC unit and we are just not sure of the market for that product so we are taking a wait and see attitude. Number one, are the car companies going to adopt this in a big way and if they do are the markets going to adopt it in a big way—and we aren't convinced." –EVSE and charging services provider*

*"**I don't see any market or regulatory barriers**. I think that is all in place in California and other states because they have attacked the distributed resources subject. I think [some] other states have some ways to go." –EVSE and charging services provider*

There are many regulatory standards and parties involved to make V2G/V2H possible. The primary groups are Underwriters Laboratories (UL), the National Fire Protection Association (NFPA), National

[65] California Public Utilities Commission, "Amended Scoping Memo and Ruling of the Assigned Commissioner and Administrative Law Judge," *California Public Utilities Commission*, 2016.
[66] Pacific Gas and Electric Company, "Pacific Gas and Electric Company's Electric Vehicle Infrastructure and Education Senate Bill 350 Transportation Electrification Program Application," *Pacific Gas and Electric Company,* 2017.
[67] Southern California Edison, "Application of Southern California Edison Company for Approval of its 2017 Transportation Electrification Proposals," *Southern California Edison*, 2017.
[68] San Diego Gas & Electric, "Application of San Diego Gas & Electric Company for Authority to Implement Priority Review and Standard Review Proposals to Accelerate Widespread Transportation Electrification," *San Diego Gas & Electric,* 2017.
[69] California Energy Commission, "Hybrid and Plug-in Electric Vehicles - DRIVE: California's Alternative and Renewable Fuel and Vehicle Technology Program," *California Energy Commission*, 2017, http://www.energy.ca.gov/drive/technology/plugin_electric.html.
[70] Laura Margoni, "Nuvve and UC San Diego to Demonstrate Vehicle-to-Grid Technology through Energy Commission Grant," *UC San Diego News Center,* June 14, 2017, http://ucsdnews.ucsd.edu/pressrelease/nuvve_and_uc_san_diego_to_demonstrate_vehicle_to_grid_technology.

Electrical Code (NEC), the Institute of Electrical and Electronics Engineering (IEEE), the Society of Automotive Engineers (SAE), automakers, local permitting officials, Departments of Transportation (DOTs), and the International Code Council (ICC). The key standards are focused around connection to the home/grid, communication to devices like vehicles, and enabling technology on the vehicle. Most of the technology issues found in vehicle technology, communication among vehicle and outside devices, and connections to the home have been addressed, and the solutions are awaiting implementation within the market. Remaining standards and technology issues do not directly need utility engagement but could benefit from utility support, such as working with government regulators on supporting warranty standards updates that allow for V2G/V2H usage. Advancement will require more demonstrations and market alignment on methods to execute the standards that have been recently created.

4.1.4.1 V2G/V2H Standards and Protocols

Interconnection of vehicle to charger, charger to home, and communications for chargers/vehicles to outside entities like the utility are governed by a complex interrelation of codes and standards. There are items of consideration at the local, state, and national levels to address.

Stakeholder Viewpoint: Opinions and Impressions of V2X and V2H

*"…these are great bi-directional tools for utilities to extract power when it's needed and forgo second tier power generation when the grid is at a saturation point. It's also become a nice revenue opportunity for the EV owner [and] valued to utilities. The difficult point becomes … where **utilities love to sell you the power but they're not so happy to buy it back** … I question how the long-term viability of V2X will work when the underlining business paradigms are not aligned along stakeholders"*
–EVSE and charging services provider

Local Standards

Permitting is driven by the local authority having jurisdiction (AHJ). Permitting an EVSE installation can be a complicated process, requiring the customer to coordinate with an electrician, the local building department, and the utility. EVSE permitting has varying levels of complexity depending on the type of charger, AHJ permitting requirements, and grid capabilities. Permitting costs, level of review, and the permit application process varies by jurisdiction. Permitting barriers include documentation, plan check requirements, dedicated metering, and capacity issues. Some efforts have been made by states to create a streamlined permitting process across jurisdictions. In California, AB 1236 mandates that a city or county with a population of 200,000 or more must adopt a streamlined permitting process for EVSE installation.[71] The Zero Emissions Vehicle: Community Readiness Guidebook outlines the standard permitting process for jurisdictions to adopt.

[71] Alternative Fuels Data Center, "Electric Vehicle Supply Equipment (EVSE) Local Permitting Policies," *US Department of Energy,* May 21, 2017, https://www.afdc.energy.gov/laws/11660.

Stakeholder Viewpoint: Outlook for V2X

"I think up until now it's been a fairly ad hoc, bottoms up planning effort that's been led by some utilities and governing institutions, I don't sense so much a centralized planning approach. It could've come from the White House or consortium to set up the go-to-market approach or the technology impediments so there's a game plan or time schedule. ***State and local entities*** *can get behind this with something to tether too, and I* ***don't sense that they're out there now****. And until that happens in a robust fashion V2X will be slow to execute." –EVSE and charging services provider*

State Standards

California Rule 21 governs interconnection of DER, providing the likely guidance for interconnecting most residential V2G/V2H scenarios. Rule 21 allows customers to install generating or storage facilitates while ensuring the safety and reliability of the grid. Customers seeking to generate power for their own use (non-export), for their own use and to sell back to the grid for credits (net energy metering), or sell all their electricity back to the grid (export) can do so under the Rule 21 tariff.[72] V2G customers would fall into the net energy metering (NEM) category and V2H customers into the non-export category. IEEE 1547, which Rule 21 is based on, has anti-islanding requirements, but due to increased penetration of DER, Rule 21 was being updated at the time of this report to allow automated reaction modes for grid support functions by allowing islanding and more advanced control rather than a single anti-island prohibition. The communication standards of the Rule 21 update could be drawn from IEEE 2030.5, also known as SEP 2.0. SEP 2.0 enables communication for SAE standard-compliant EVSE, and defines the framework that enables secure interactions between IOU servers and clients, helping to assist with grid stability.[73]

The California Green Building Standards Code Title 24, Part 11 (CALGreen) was developed to improve public health and safety and environmental impacts through green buildings. Part 4.106.4.1 of CALGreen describes EV charging requirements for new construction to make charging station installation more accessible and to help promote California's emission targets. Single-family residential units with attached private garages are required to install a raceway to accommodate a dedicated 208V/240V branch circuit for each dwelling unit.[74]

National Standards

Vehicle-related standards typically flow from the SAE, but can also be found within UL and IEEE standards. Grid connection standards are defined primarily by UL and portions of the NEC, which is defined in NFPA standard number 70. The key UL standards regarding vehicle charging and discharging are:[75]

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[72] California Public Utilities Commission, "Rule 21 Interconnection," *California Public Utilities Commission*, 2017, http://www.cpuc.ca.gov/General.aspx?id=3962.

[73] IEEE, *2030.5-2013 – IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard*, (Standards Development Working Group), https://standards.ieee.org/findstds/standard/2030.5-2013.html.

[74] California Building Standards Commission, *California Building Standards Code,* 2016, http://www.bsc.ca.gov/Home/CALGreen.aspx.

[75] Underwriters Laboratories, *Standard for Electric Vehicle Supply Equipment*, 2017, https://standardscatalog.ul.com/standards/en/standard_2594.

- UL 2594, which covers conductive EVSE and applies to Level 1 and 2 charging
- UL 2202 is similar to 2594 but covers DC fast charging
- UL 9741 (Safety of Bi-directional Electric Vehicle Charging Systems and Equipment) covers requirements on bi-directional electric vehicle charging equipment and includes functionality to export power from the EV to an electric power supply

The communication protocol between vehicle, EVSE, and external entities like the local grid manager, is provided primarily by the SEP 2.0 standard and IEEE 2030.5.

Stakeholder Viewpoint: Challenges to Implementing V2X

Most interviewees did not think there were any technical or communication protocol barriers to successfully implementing V2X technology. One stakeholder noted the need to ***avoid having multiple standards****.*

"…a good environment for development is ***not having multiple standards*** *to adapt to or trying to come up with in the first place" –EVSE and charging services provider*

"When we talk about the ***biggest barriers****, on one hand you* ***have [safety standards] at the forefront.*** *The other piece is...the propagation of the technology. Looking at varying cases, you have competing ecosystems and communication protocols, but eventually there will be that tipping point…but it's a matter of when." –EMS technology developer*

Vehicle Plug Standards

SAE is the organization that develops standards for charging equipment made in the United States. The International Electrotechnical Commission (IEC) defines charging station equipment standards globally. IEC 62196 is the global standard that includes plugs, socket-outlets, vehicle couplers and vehicle inlets. The SAE standards are incorporated into IEC standards and standards for charging couplers made outside of the U.S. are also incorporated into the IEC standards. Below are four plug types incorporated into the IEC standards:

- SAE J1772 or the Yazaki connector made in North America
  - The CCS also has a J1772 plug with two additional pins for DC fast charging
  - Tesla's DC Supercharger has a J1772 adapter and is also covered under SAE standards
- JEVS G105-1993, commonly known as the CHAdeMO, is made in Japan
- VDE-AR-E 2623-2-2, also known as the Mennekes connector, is made in Europe
  - This plug is not common to the U.S.
- EV Plug Alliance proposal, also known as the Scame connector, is made in Italy
  - This plug is not common to the U.S.

The equipment incorporated in the IEC 62196 standards also have communication standards for communication between the EVSE, EVs and the grid. Communication from the EV to the EVSE is based on ISO/IEC 15118 standards for AC charging and IEC 61851-24 and ISO/IEC 15118 for DC charging. Communication from the EVSE to the grid for unidirectional or bidirectional charging is based on IEC 61850-7-420. IEC 61850-7-420 defines information models to be used in the exchange of information with DER, including EVs. Part 7-420 is currently a work in progress and its forecasted publication date is 12/26/2017.

As mentioned above, the SAE provides the standards related to the vehicle itself and how it works in a V2G/V2H implementation. Key standards are listed below, and all remaining SAE standards are provided in Appendix A.[76]

- SAE J2847 specifies communication protocols and messaging.
  - SAE J2847/2 establishes requirements and specifications for communications between PEVs and DC offboard chargers
  - SAE J2847/6 establishes requirements and specifications for communications messages between wirelessly charged EVs and wireless chargers
- SAE J2954 specifies acceptable criteria for interoperability, electromagnetic compatibility, minimum performance, safety, and testing for wireless charging of light duty electric and PEVs. This includes standardizing wireless power transfer (WPT) at certain power levels. So far this includes WPT1 (3.7 kW) and WPT2 (7.7 kW). Standards for WPT3 (11 kW) and WPT4 (22 kW) will be specified in future revisions of SAE J2954.
- SAE J2836/6 establishes use cases for communication between PEVs and EVSE for wireless energy transfer as specified in SAE J2954, addressing requirements for communications

[76] SAE International, *Vehicle Electrification Standards*, 2017, http://www.sae.org/standardsdev/vehicleelectrification.htm

between onboard charging systems and the wireless EVSE for detection, the charging process, and monitoring of the charging process.

Figure 10 outlines key standards impacting V2G and V2H implementation, as well as regulatory considerations.

Figure 10. Key V2G and V2H Standards and Regulatory Considerations

SEP 2.0 / IEEE 2030.5

- Price & billing communication
- Demand response
- Load control
- Energy usage / Meter data
- DER communication
- Software updates

NEC / NFPA 70

- Power connection / interconnection
- Safety standards
- Testing guidelines for confirming standards compliance
- Focused primarily on building to EVSE

SAE

- Communications between vehicle and external devices
- Safety standards
- Testing guidelines for confirming standards compliance
- Focused primarily on vehicle and its interactions with outside devices

Additional Potential Regulatory Considerations

- Zero net energy building standards / CAL Green code
- Local building permitting guidelines (EVSE make ready and required inclusion)
- Local fast track permitting requirements
- Renewable power requirements (impacted by load additions of PEVs)
- DER interconnection (IEEE 1547)
- UL standards

Figure 11 highlights standards and codes listed by the area of VGI that it affects, with relevant descriptions. While some standards only affect one area of V2G/V2H, others play a role in multiple.

Figure 11. Standards and Codes by Topic Area

Standard / Code	Group	Relevance
IEEE 1547 CA Rule 21	Infrastructure Dispensing	Interconnections to Grid
IEEE 2030.5 SEP 2.0	Infrastructure Dispensing Vehicles	Communications between Vehicle, Charger, and Home Energy Management System
CA Rule 2	Infrastructure	Voltage and Frequency Standards
IEEE 519	Dispensing	Addressing Ability to Handle System Interference (PQ)
NFPA 70 NEC 625	Dispensing	Safety Requirements of the Electrical Code
SAE J1772	Vehicles	Connector only used for absorbing and exporting EV traction battery
UL 1741	Vehicles	When operating residential storage battery, PV and EV off board inverter only

Default Time-of-Use Rates

In July 2015, CPUC Decision 15.07-001 provided specific steps IOUs must take to reform residential rate structures across California. This rate reform will culminate in default time-of-use (TOU) rates for all residential customers in IOU service areas in the state by 2019. By January 1, 2018, IOUs must file a residential rate design window application that proposes the default TOU rate structure.

Implementing default TOU rates in the coming years could prompt customers to become more engaged in how they use their electricity. For those interested in exploring options to help offset any potential increases in charges and fees (real or perceived) under the new structure, V2G/V2H could be an area of interest. As characterized in this report, the current V2G/V2H technologies and market conditions are not commercially ready in the United States. Further development, commercialization, and market adoption of these technologies is needed before they can provide a potential option for customers who seek more control over their power usage relative to their TOU rate schedule. Consequently, the intersection of residential TOU rate rollout in California relative to V2G/V2H market developments is an area worthy of monitoring and tracking for California utilities and other stakeholders going forward.

4.1.5 Conclusions

Vehicle-to-Grid Beginnings and Background

Based on the history of V2G technology, most testing and demonstrations occurring today grew out of UD's initial test pilots. Overall, there has been an increase in the number of demonstrations taking place globally in recent years, indicating more support and funding for advancing these technologies despite barriers currently in the market.

Technology, Market, and Generational Testing

Several barriers to commercialization exist for V2G and V2H technologies in the United States. OEMs are unwilling to mass produce grid-integrated vehicles until more testing has been completed and vehicle warranty issues are resolved. Currently, not all necessary technology is equipped to participate in grid services, also dependent on more testing. From a utility standpoint, 100 kW of guaranteed minimum capacity for DR is typically required before a utility will allow new market entrants to participate in grid services. Based on technology barriers preventing V2G and V2H commercialization, the trend in the market leads to a need for continued testing, especially in residential and commercial settings.

Regulatory Examination

There are several areas where standards are still being defined that could have a material impact on the evolution of the V2G/V2H space. Many of the items that fall within this category are already actively being developed and are expected to be finalized within the next couple of years. There are other areas that are defined but do not yet have an active approach developed. For example, the communication protocol to accomplish basic tasks in controlling the charging and discharging of battery-based systems is defined via IEEE 2030.5, but there is not a best practice approach for market participants to implement the actual communication protocol among market participants and balancing authorities. Consequently, there is no clearinghouse for EVSE and automotive OEMs to use in developing systems that could be ready to connect and work right away with a variety of utility systems. An example standard underway is IEEE P825 for integration of DER with grid systems. Additionally, several new companies have emerged offering services to connect the dots as an integrator between the major players.

Both national and state regulations establish warranty minimum viability requirements for automotive batteries based on mileage and/or absolute age requirements. These requirements need updating to an hours-of-use standard—similar to aircraft standards—to align warranty conditions with usage like travel or V2G/V2H cycling. OEMs are not expected to push or support V2G/V2H until this issue is resolved. Once warranty minimum viability requirements are in place, OEMs could rapidly update vehicle warranties, albeit unlikely in a retroactive fashion. Such updates are needed at federal and California ZEV program levels. While the legislative effort needed would likely be minimal, stakeholders have focused on other priorities up to this point.

Overall, V2G and V2H standards are slowly becoming more aligned with market requirements, but there are still key areas that require standardization before V2G/V2H products can be commercialized. Most technical issues have been addressed in the regulatory space but are awaiting implementation in the market.

4.2 Task 2: V2H Demonstration Setup, Test Plan, and Testing

To validate the technical execution of this project, PG&E developed 70 test scenarios involving varying combinations of residential stationary storage, solar PV, and an EV. The testing was designed by PG&E to find issues between handoffs or transitions between these key three components under several key situations involving islanding from the grid, as well as a limited number of grid-connected scenarios. Notably, only one test (Test 70) showed an issue with Rule 2 for further investigation.

4.2.1 PG&E EPIC 2.03b V2H Demonstration

In service of the EPIC program charter, PG&E's EPIC 2.03b project sought to demonstrate new and novel V2H technology applications and estimate potential ratepayer benefits associated with deployment.

Recently, there has been an increase in market offerings for residential stationary storage. Simultaneously, automakers are testing aggregated VGI functionality in projects like the PG&E and BMW iChargeForward demonstration. This project aimed to understand if there were benefits in an islanded situation for each of these two technologies through two net new V2H testing questions:

- ***Battery vs. Vehicle:*** Can a vehicle replace the hard islanding and DR functionality and benefits of a stationary storage device?
- ***Battery plus Vehicle:*** Are there incremental hard islanding and DR benefits from using both stationary storage and a vehicle to provide a better solution?

Stakeholder Viewpoint: Opinion and Impressions of V2X and V2H

*Some stakeholders felt that **stationary batteries will reduce demand for V2X** technology; EVSE-focused respondents were less likely to see opportunity than software-focused respondents.*

*"…as stationary batteries grow and deploy in volume, you'll see **prices diminish for grid services** that form the basis of this market, so stationary will be much more competitive than mobile battery sources and so there isn't really a need for V2G in our view. …stationary battery to grid service will be the dominant model." –EVSE and charging services provider*

*"Everything we see in the battery storage industry–looking at the growth of electric vehicles, [they] **all have a storage system attached to them**. It's only a matter of time before [this technology]…becomes a reality." –EMS technology developer*

*"A lot of customers have solar in their homes, but not a lot have stationary storage at this point—but that's **becoming more prevalent**. Maybe my neighbor will put in solar and I'll put in stationary storage and I'll charge my storage off of his solar—none of the power would come from the grid." –OEM*

Lab Test Goals

The lab test goal was to demonstrate whether an EV capable of bi-directional power flow alone or combined with stationary storage and solar PV, can power a customer's home during a DR event or outage. To achieve this goal, testing sought to show compliance with criteria from Utility Rule 2. PG&E's ATS group performed validation tests to establish all transition states and changes for the various key hardware components participating in the demonstration. Table 7 provides descriptions for the success criteria used in the tests.

Table 7. Validation Testing Success Criteria

Success Criterion	Description
Islanding (Outage / Demand Response)	Initiate electric service to a home from an energy resource behind the point of common coupling in response to loss of electric utility power, either due to demand response (signal initiated) or outage conditions
Paralleled Resources	Ability to operate in parallel with other energy resources such as PV and energy storage, and transition between resources
Cold Load Pickup	Ability to instantly pick up load in accordance with Rule 21
Rule 2 Voltage Range	Ability to maintain residential voltage within the Utility Rule 2 voltage range
Load Following	Ability to follow the load pattern, as applied to the load bank simulating demand for a residential service point

Lab Test Design

The testing took place at an installed demonstration site at ATS with an EV with power export capabilities. PG&E's ATS group modified a fleet plug-in hybrid electric truck for testing purposes to have bi-directional power flow in an export (60 kWh, 15 kW max export) capability. The solar PV utilized was rated as a 5 kW system and the stationary storage was 5 kW output and 8.6 kWh capacity. The demonstration used different load shapes and combinations of the EV, stationary storage, and solar PV resources to produce the test results related to specific environmental scenarios. Each scenario models performance of these key components at several time points within simulated outage and DR events, including ramping into, during, and transitioning out of events. By testing the system through the scenarios outlined later in this section, this project found there was sufficient data to address the project objectives, including the net new research questions outlined above.

The test scenarios included several assumptions:

- Vehicle battery draw down under a minimal EV range impact condition was set at 10% of battery capacity (defined as 6 kWh for this test).
- Vehicle battery draw down under a maximum support condition was set at 50 kWh (83% of total capacity for this test). This ensured a small drivable range and minimum SOC maintenance for protecting battery life.
- Hourly home energy use load profiles were generated through Snapshot Efficiency,[77] an energy policy research tool administered by the IOUs in California. Generating and testing 8760-hour load profiles for new and existing homes in every PG&E climate zone was not practical within the project timeframe, nor a wise use of ratepayer funds at this exploratory stage in V2H investigation. Consequently, thus the project utilized new residential single-family home load profiles in the Oakland and Fresno climate zones[78] to represent areas in PG&E service territory experiencing EV adoption with low (Oakland) and high (Fresno) home energy use, respectively. All inputs to the Snapshot Efficiency Tool are detailed in Appendices D and E.
- Definition of nanogrid is an islandable, single building load less than 100 kW.[79]
- ATS used an inverter at various intervals below 5 kW max. This approach is relevant as the California Independent System Operator (CAISO) signals are based on the percent kW nameplate reduction; not actual kW reduction that places more emphasis on the need to bound the duration of DR events to modulate accordingly.
- Installing a manual transfer switch between the utility and main panel was not considered to be a viable option for this demonstration due to cost. Such a switch would allow a customer to manually island the home from the grid, rather than an automated response to an outage.

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[77] Pacific Gas and Electric Company, et al., "Snapshot Efficiency," *California Public Utilities Commission*, https://snapshotefficiency.com. Snapshot Efficiency is a tool designed to assist with early-stage energy policy research. It is particularly helpful at iterating through efficiency measure combinations and assessing the comparative benefits of strategies. Before using results from Snapshot Efficiency to adopt policies, independent analyses should be performed using alternate analytical models and data sources. Snapshot Efficiency is funded by California utility customers and administered by Pacific Gas and Electric Company, Southern California Edison, San Diego Gas & Electric Company and Southern California Gas Company under the auspices of the California Public Utilities Commission.

[78] California Energy Commission, Climate Zones 3 (Oakland) and 13 (Fresno): http://www.energy.ca.gov/maps/renewable/building_climate_zones.html

[79] Islandable, single building load less than 100 kW; Navigant Research, "Microgrid Multi-Client Study," *Navigant Consulting Inc.,* November 30, 2015.

4.2.2 V2H Test Scenarios

Table 8 details the EPIC 2.03b test scenarios that inform V2H performance in terms of the net new V2H research questions. An exhaustive list of the test scenarios containing descriptions, narrative and results can be found in Appendix C. The primary equipment used in the testing included load banks (to simulate load with varying conditions and set points), stationary storage, solar PV, and the EV. There are two types of scenarios: verification and validation. Verification scenarios illustrated the capability of the system to perform with and without the EV. Validation scenarios tested the capability of the EV to perform under varying conditions and with different combinations of equipment.

Table 8. Summary of Key Testing Scenarios

Scenario	Description	Test Number	Primary Equipment		
			SS	PV	EV
Verification	Residential stationary storage baseline performance without solar PV	14, 17-26, 33-35, 39-58	X		
	Residential stationary storage baseline performance with solar PV	15-16, 27-32	X	X	
Validation	Electric Vehicle (EV) supporting residential load in an Island mode, varying conditions	1, 69			X
	EV supporting residential load in an Island mode. EV acting in Grid Support Mode, varying cold load pickup in 1 kW increments.	2-6			X
	EV supporting residential load in an Island mode with PV, varying conditions	7-13, 70		X	X
	EV supporting residential load in an Island mode with SS, varying conditions	66	X		X
	EV supporting residential load in an Island mode with PV and SS, varying conditions	36-37, 67-68	X	X	X

Notably, the rationale for selecting these test scenarios was that they are most likely to occur in a real-world V2H configuration in the near-term to operate in a demand response or outage condition. PG&E recognizes that this use case list is not exhaustive, and therefore does not reflect the universe of potential issues that V2H systems could encounter. Nevertheless, PG&E believes the results from the use cases were instructive to advancing the understanding of potential combinatorial configurations of various components operating in a V2H configuration under varying conditions.

4.2.3 Lab Test Results

The testing execution focused on, and successfully demonstrated, the feasibility of the EV and SS to capture excess solar PV energy, act as current and/or voltage sources, act as frequency generators to enable solar PV to function in islanded situations, and properly transfer and handle cold loads in loss of grid situations—all while maintaining safety and operating within utility requirements.

Table 9 summarizes the test results relative to the success criteria established for the project.

Table 9. V2H System Test Results

Scenario	Primary Resource(s)	Success Criteria Tested				
		Islanding (Outage / Demand Response)	Paralleled Resources	Cold Load Pickup	Rule 2 Voltage Range	Load Following
Verification	SS	Pass	Pass	Pass	Pass	Pass
	SS + PV	Pass	Pass	N/A	Pass	Pass
Validation	EV Islanded	Pass	N/A	N/A	Pass	Pass
	EV Islanded + Grid Support Mode	Pass	N/A	Pass	Pass	N/A
	EV Islanded + PV	Pass	Pass	Pass	Pass (7-13) Fail (70)	Pass
	EV Islanded + SS	Pass	Pass	Pass	Pass	Pass
	Nanogrid	Pass	Pass	Pass	Pass	Pass

Notably, the only instance of failure was in Test 70 where the EV export slightly exceeded the voltage requirements set forth under Rule 2. Under this voltage condition, voltage sensitive components on a user's home power network may encounter issues, such as triggering crashes for a desktop computer during the short-term window of the voltage non-conformance. While this condition might not trigger any such issues in practice, the result is worth noting as it does potentially create a situation where impacts could occur, and is worthy of additional testing. Further details on Test 70 are included below.

The overall successful V2H System test results provided the following key findings that satisfied the testing goals of the project, and validated the pursuit of a cost-benefit analysis of V2H technology in the subsequent project tasks:

- EV demonstrated the ability to support the islanding mode of a residential load, allowing critical loads to continue (Test 1).
- EV demonstrated the ability to handle between 1 kW and 5 kW of cold load pickup (Tests 2-6).
- In several testing scenarios, solar PV was added to export to the critical panel in parallel with the EV (Test 7-13).
- EV was able to utilize excess solar PV load for charging purposes when critical loads were met (Test 68).
- EV and solar PV successfully entered islanding mode in cold load pickup scenarios, with the goal of having EVs support the load safely and continuously and within utility requirements (Test 69), while identifying an opportunity for additional testing of large PV load impacts on V2H system voltage (Test 70).

Key implications from lab tests results include the need for hardware improvements that simplify installation and operation at reduced costs and additional testing of voltage sensitivities for eventual standards compliance.

The following summaries describe the validation tests that produced each of the key findings.

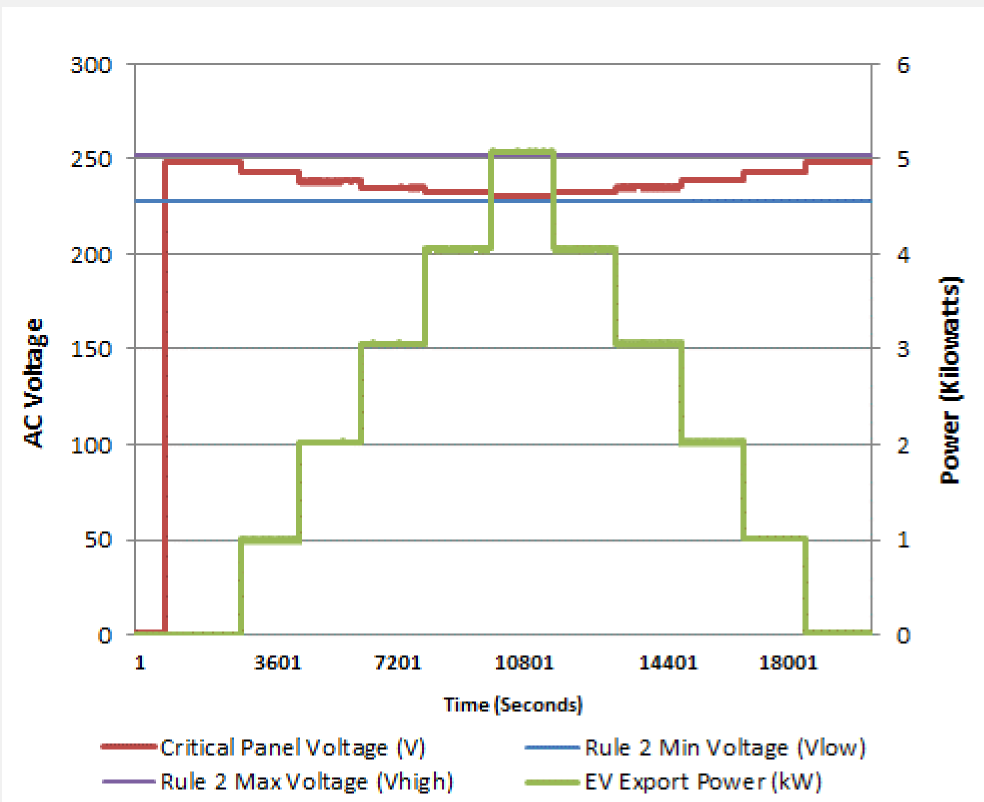
Test No. 1

Description: Demonstrates that EV follows and supports residential load in an Island or demand response configuration at the critical panel.

Narrative: Disconnected and isolated the connection to the utility. All residential critical loads were sourced to the EV. The EV was set to export limited power to support only critical loads. PV was not active, loads ramped up and then down 1 kW at a time to test ability of EV output to follow load. PV and stationary storage were not involved in this test. For testing purposes, the EV Inverter was not specified to operate in accordance with Utilities Rule 21 (Anti-Island).

Results: EV acted as primary source of residential power. EV output voltage stayed within Utilities Rule 2 (within 5% of nominal). Graph of load line not shown in Test 1 graph below because EV Export Power is matching and following load very closely (lines would appear to overlap perfectly).

Test 1: EV Load Support in Islanded Service



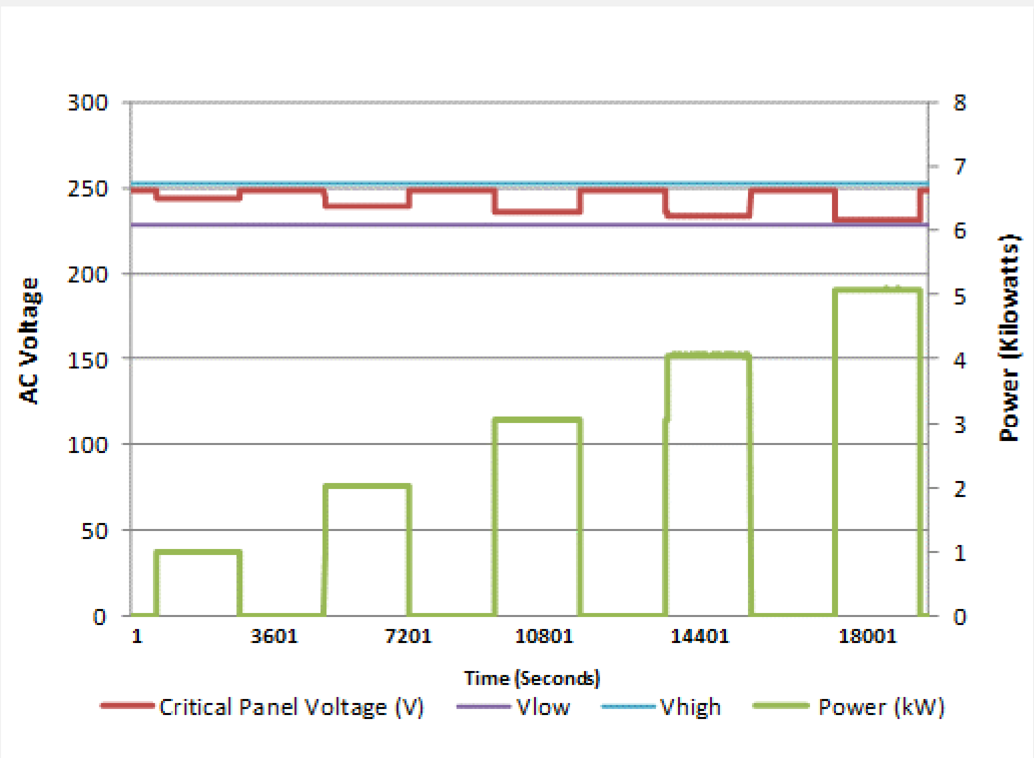
Tests No. 2 through 6

Description: Demonstrates that EV supports residential load in Island mode, testing 1 kW to 5 kW Cold Load pickup, simulating instantaneous outage conditions.

Narrative: This test was initiated with loads initially set to zero. Connected EV to critical panel. Electric Vehicle was set to follow critical load, and performed a Cold Load pickup of 1 kW to 5 kW. Cold Load is defined as the immediate request for power at a specific power level.

Results: Electric Vehicle demonstrated successful load support throughout varying Cold Load pick up levels, safely and continuously, and within Utility specifications for voltage control.

Test 2 through 6: EV Supports Varying Cold Load Pickup in Islanded Mode



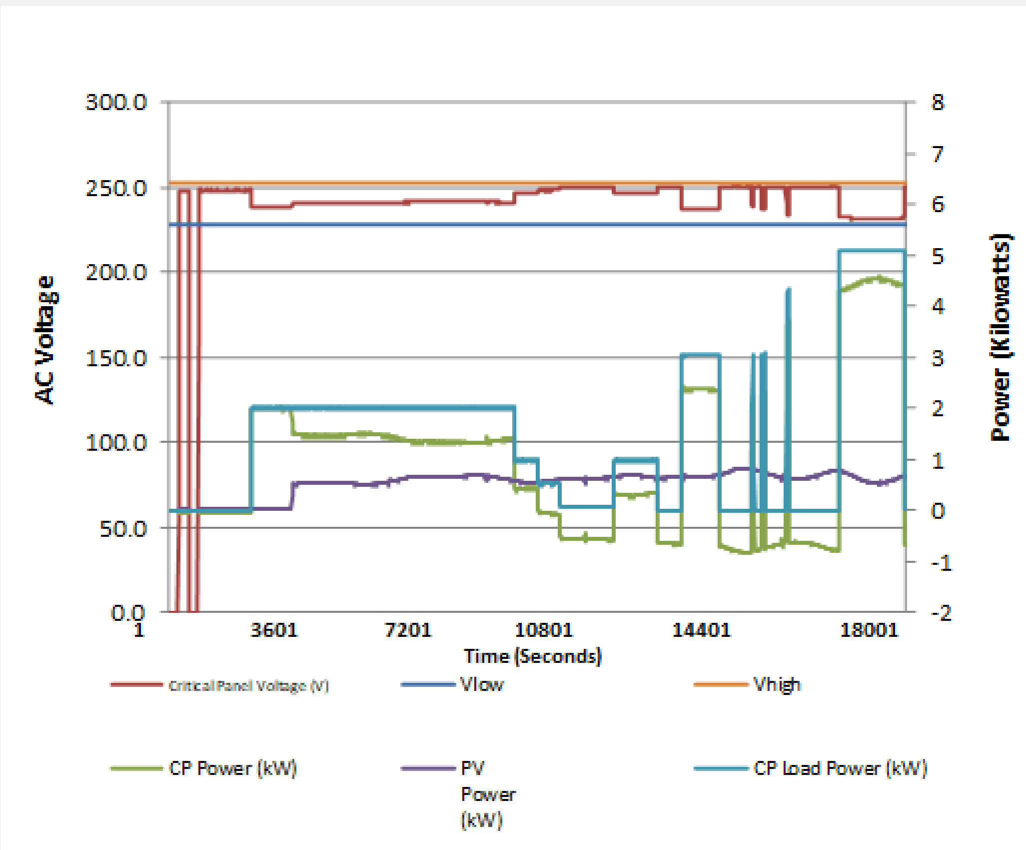
Tests No. 7 through 13

Description: Demonstrates that EV supports V2H load-following in parallel with PV under varying conditions and transitions. Electric Vehicle export set in Island mode, with PV in parallel exporting in accordance with the PV output model. Critical load varied such that PV outputs more than required for the residential load and charges the EV. Cold Load Pickup tested at 3 kW and 4.5 kW.

Narrative: Critical loads start at zero. Electric Vehicle connected to critical panel and follow critical load. Applied and paralleled PV. Performed a Cold Load pickup. Goal was to test whether the EV can support load safely and continuously, and within Utility requirements. As critical panel load decreases, test increased the charge level on the EV. This allowed the vehicle to utilize the PV export, thus preventing the PV from tripping "OFF". Electric Vehicle is tested to absorb power, while at the same time also act as the Voltage Source or Frequency Generator.

Results: EV demonstrated the capability to act as a voltage or frequency source, allowing PV to successfully connect to the Critical Panel. Further demonstrated the ability to pick up cold load during the test. During tests, critical panel voltage is demonstrated to stay within Utility Rule 2.

Test No. 7 through 13: Islanded Home with EV in Parallel with PV and Cold Load Pickup



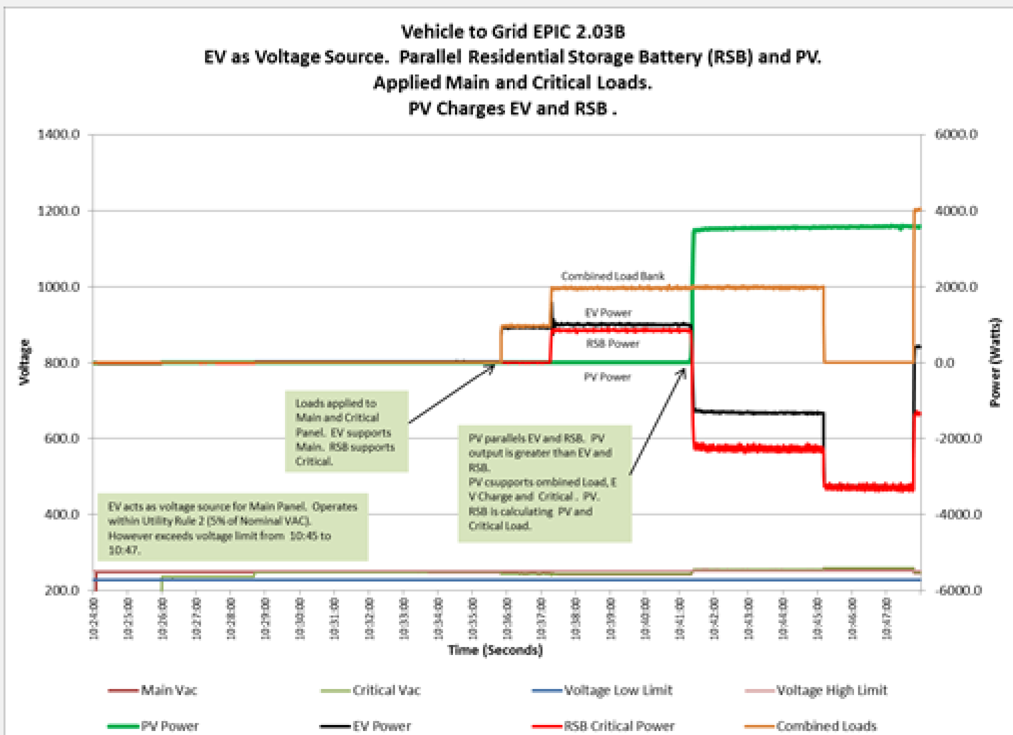
Test No. 68

Description: Demonstrates EV acting in voltage source mode, paralleled EV with PV and residential storage battery, and charging EV as load transitions below household load.

Narrative: This test demonstrates the capability of the PV to charge the EV, with the EV acting in bi-directional mode. Loads are applied to simulate normal residential conditions. The residential storage system is paralleled with the EV. Loads are applied to both main (1 kW) and critical (1 kW) panels. PV is finally energized to test for capability to parallel with both EV and battery, then load is decreased.

Results: Although EV was acting as the voltage source, the EV successfully absorbed power from PV using the bi-directional inverter as household load decreased below PV output, demonstrating desired parallel operation between EV, SS and PV with varying load conditions.

Test No. 68: EV in Voltage Source mode with PV charging EV paralleling SS



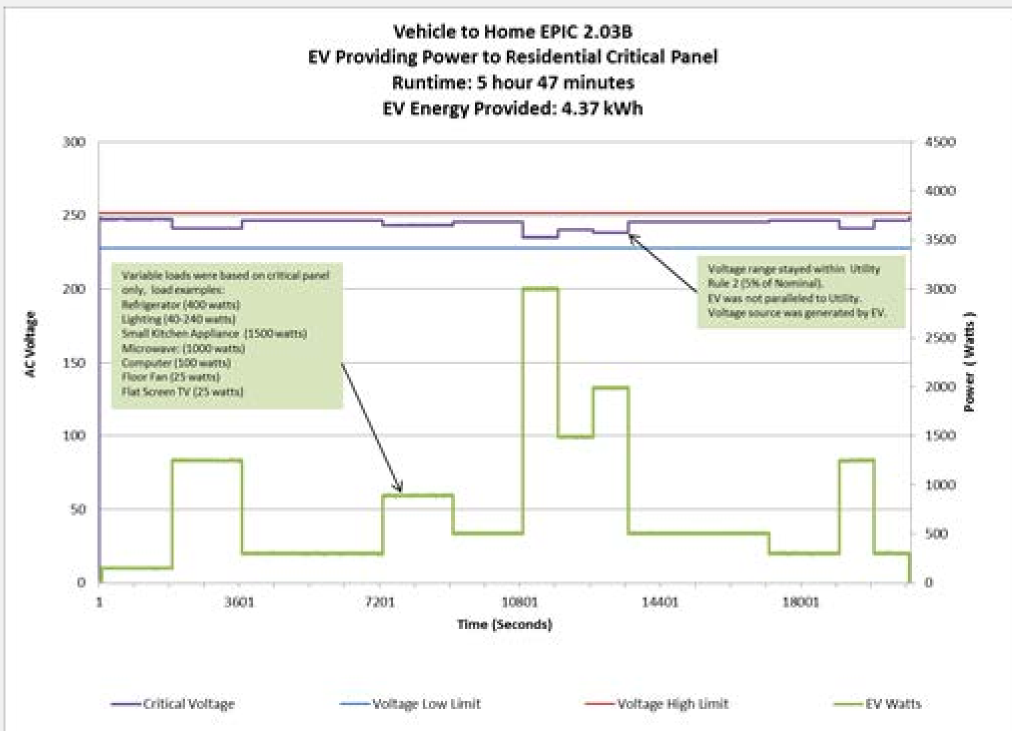
Test No. 69

Description: Demonstrates EV, acting in Voltage Source mode, with the system islanded from the utility simulating an outage. The main panel load is set to zero, with critical load only. Variable load in accordance with the residential load profile for a 5-hour test, with no PV applied.

Narrative: Purpose of tests was to demonstrate that the EV can support the critical load panel with varying load-following conditions in the event utility power was not available due to an outage.

Results: EV was demonstrated to successfully support critical variable load for 5 hours. Voltage level was demonstrated to stay within Utility Rule 2 throughout the test period.

Test No. 69: Islanded Home with EV in Voltage Source Mode with Varying Critical Loads



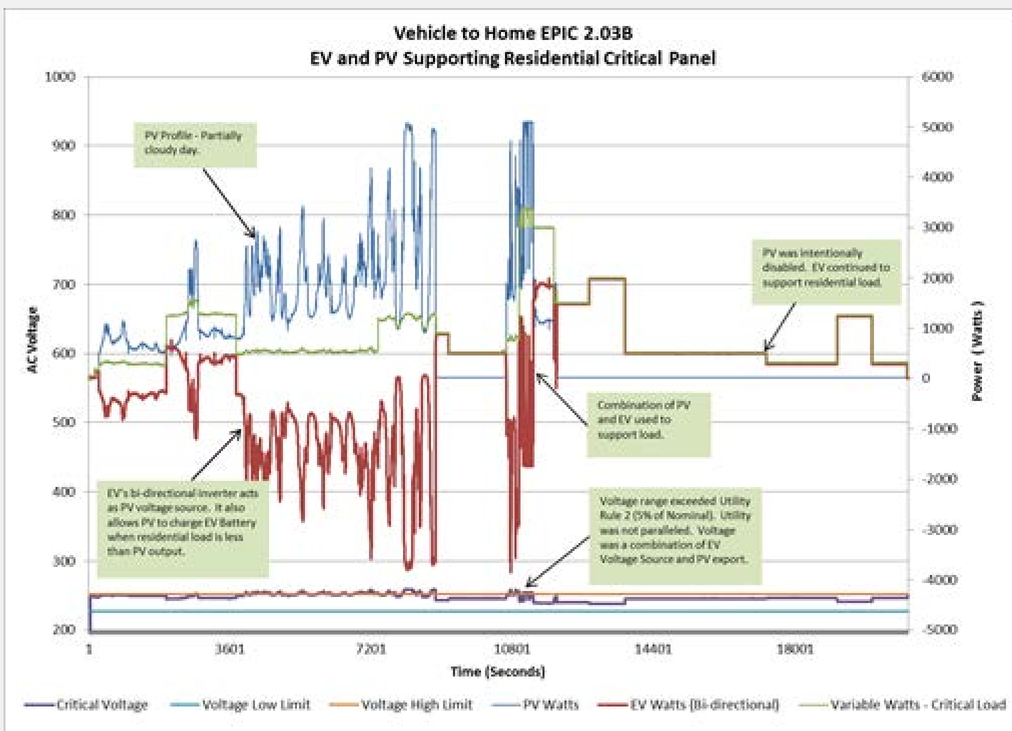
Test No. 70

Description: Electric Vehicle acting in Voltage Source mode, Utility not present. PV applied in parallel with EV on the critical panel. Critical panel loads only. Variable 5-hour load in accordance with residential load profile.

Narrative: Purpose of tests was to test whether the vehicle can support the critical load panel in the event Utility power was not available. With EV acting as voltage source, applied and activated the PV paralleled to the critical panel. PV not in current source mode. Applied a variable load to the critical panel.

Results: EV and PV demonstrated the ability to successfully support critical variable load while in parallel, while the EV set in voltage source mode, for a 5-hour test period. Notably, EV voltage did exceed Utility Rule 2. Data also indicated the distribution of power between EV and PV. As residential load decreased, EV would absorb any additional power from PV. If EV SOC was 100%, and not able to accept power from PV, PV demonstrated its ability to trip.

Test No. 70: Islanded Home with EV in Voltage Source Mode with PV and Varying Critical Loads



4.3 Task 3: Cost-Benefit Analysis Framework

The following section covers the approach to developing the cost-benefit analysis (CBA) framework.

4.3.1 Overview of Cost-Benefit Framework

The CBA framework was developed in four steps:

1. Establish relevant perspectives
2. Document data requirements
3. Score data based on criteria
4. Assess the inputs and results for inclusion in a data library

This framework identified the relevant cost-benefit perspectives for V2H technology including customer, ratepayer, utility, and societal stakeholders. Appendix F details all data requirements, sources, and proposed approaches for calculating the variables associated with each perspective. PG&E assessed the suitability of each variable for inclusion in the modeling and analysis based on the following scoring criteria:

- **Data Availability:** Availability of primary data within project timeline, scope, and budget.
- **Data Quality:** Suitability of data to calculate intended variable and the relevance of the data source.
- **Data Cost:** Expected cost to collect primary or secondary data.
- **Calculation Methodology:** Suitability of the calculation methodology.

A data library was created to store the final variables determined to be suitable for the analysis.

After developing the framework, PG&E proceeded to conduct the analysis. The framework accounts for the incremental value of the technologies over those that exist in a hypothetical EV customer baseline home described in the subsequent section.

The V2H Cost-Benefit Analysis monetized net benefits of bi-directional V2H charging infrastructure and stationary storage to provide a net new comparison in the following scenarios that PG&E deemed most relevant to EPIC objectives:

1. Three stakeholder perspectives based on standard cost tests used to measure cost-effectiveness of energy savings investments per the California Standard Practice Manual[80]:
    a. Customers/homeowners (participant cost test – PCT)
    b. Program administrators/PG&E (program administrator cost test – PACT)
    c. Society/regulatory agencies (total resource cost test – TRC)

[80] California Public Utilities Commission, "California Standard Practice Manual – Economic Analysis of Demand-Side Programs and Projects", *California Public Utilities Commission*, October 2001: http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy_-_Electricity_and_Natural_Gas/CPUC_STANDARD_PRACTICE_MANUAL.pdf

2. Three technical configurations, which aim to test the islanding and DR capabilities of an EV over, or in combination with, a stationary storage device:
    a. Bi-directional V2H charging (EV)
    b. Stationary storage battery (SS)
    c. Bi-directional V2H charging combined with a stationary storage battery (EV + SS)
3. Two specific conditions, which aim to test the feasibility of bi-directional charging for specific grid and customer services:
    a. DR event participation as a resource in PG&E's CAISO supply-side pilot (SSP) program[81]
    b. Carrying loads through average and long-duration outages

4.3.2 Boundaries and Assumptions

This study narrowly defined the scope of the cost-benefit analysis, which allowed the analysis to focus on the novel aspects of the framework. Due to the limited scope of certain aspects of the framework, PG&E identified areas for future investigation, which are summarized below in Section 4.4.3 .

Baseline

V2H technology has yet to be commercialized for load management, meaning the analysis required several key assumptions. PG&E calculated all costs and benefits of participation on a per-home basis, assuming future participation volumes will be sufficient to fulfill DR program participation requirements, such as PG&E's CAISO SSP program.

As previously mentioned, the framework accounts for the incremental value of the technologies over those that exist in a hypothetical EV customer baseline home. PG&E assumed that the baseline home is equipped with an EV attached to a unidirectional charger, an EMS, and solar PV array. The EMS is assumed to be part of the baseline because, in the test case scenarios discussed in the following section, either the bidirectional charger or stationary storage would serve this function for the V2H system. This baseline home would be unable to participate in DR events or carry critical loads through outages. Importantly, because the unidirectional charger, EMS, PV, and EV are considered to be owned by the EV customer as part of the baseline, the cost for those assets is not included in the analysis.

Table 10 displays the capital costs associated with the V2H system used in the cost-benefit analysis that are ***incremental*** to the baseline capital costs for a Level 2 unidirectional charger without communication capability, EMS, PV, and EV. Additional electric critical panel upgrade components were assumed to be customer-provided (see Table 5) and not costed in the analysis, including: transfer switch; panel equipment; switch box; and installation labor for each component.

[81] The CAISO SSP requires a 100 kW load reduction sustained for 4 hours as a minimum bid during resource adequacy periods on non-holiday weekdays. Assuming approximately 3.3 kW per EV and that 10% of customer vehicles are available and at a sufficient state of charge for 4 hours, 30 homes would be needed as active participants to meet the 100 kW minimum; thus, enrollment in the program at scale would be a minimum of roughly 300 homes.

Table 10. V2H Cost-Benefit Test Case Assumptions – Incremental Capital Cost Values[82]

Equipment Assumption	Equipment Cost ($/charger)	Installation Cost ($/charger)	Total Incremental Capital Cost ($/charger)
Bi-directional SEP 2.0-capable Level 2 charger (*hypothesized*)[83]	$900[84]	$1,500[85]	**$2,400**
Residential SEP 2.0-capable storage battery	$6,200[86]	$2,000[87]	**$8,200**

Test Case Scenarios

The analysis examined three technical scenarios in the test case: an EV (bi-directional charger), stationary storage, and the EV combined with stationary storage. The project determined the energy use of the home using load profiles from Snapshot Efficiency,[88] an energy policy research tool administered by the IOUs in California. The analysis used a 50-50 weighted average of simulated residential home loads in the Oakland and Fresno climate zones to approximate a typical home receiving PG&E electric service. All inputs to the Snapshot Efficiency Tool are detailed in Appendices D and E.

As depicted in Figure 5, the test case home has a unique system configuration with a critical panel—consisting of HVAC, plug loads, cooling and refrigeration—and a main panel. The solar PV system feeds power into the home first to the critical panel, then the main panel, and then the grid (net metering). The EV and stationary storage are only configured to discharge into the critical panel, not the main panel or the grid (V2H, not V2G). During an outage, the solar PV can serve the critical panel while recharging the EV and/or stationary storage.

The configuration was designed to comply with the current execution of IEEE 1547 and Rule 21 discussed in Section 4.2.1 . Per Rule 21, operators of charging stations with energy storage are currently prevented from export.[89] The CBA commensurately assumes that during a DR event, the critical panel is the disconnect point for utility service. Consequently, in the analysis the only resources dropped from grid service and served by the V2H system are attached to the critical panel (*i.e.*, the EV only discharges to the critical panel). Notably, the volume of load served by the V2H system during DR and outage events would increase if Rule 21 allowed an EV installed behind the point of common

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82 Sources for each item are available in the data library.
83 Hypothesized because DC chargers are not currently commercially available in the residential market
84 Based on the Clipper Creek HCS-50P charger model
85 Home Advisor, "How Much Do Electric Vehicle Charging Stations Cost to Install at Home," *Home Advisor*, http://www.homeadvisor.com/cost/garages/install-an-electric-vehicle-charging-station/.
86 Based on measure characterization from Navigant project database
87 Based on measure characterization from Navigant project database
88 Pacific Gas and Electric Company, et al., "Snapshot Efficiency," *California Public Utilities Commission*, https://snapshotefficiency.com.
89 California Public Utilities Commission, Energy Storage Proceeding (Rulemaking R.10-12-007), "CPUC Energy Storage Use Case Analysis, Demand Side Management, Storage co-located with EV charging station", California Public Utilities Commission, 2012: http://cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=3145

coupling to parallel with grid service. The methodology considered how each system configuration determined the hours of outage resiliency in the case of a rare large outage event.

The customer participated in DR events with the EV and/or stationary storage and used the EV and/or stationary storage to carry load through any outages. PG&E assumed the customer operated the EV according to typical commute patterns. The EV was only considered available if the typical commute patterns indicated it was parked and, therefore, not intended to be used during the event. If the DR event is inconvenient for the customer (requires them to not use their EV) it was assumed they would opt not to participate. DR event parameters were based on the resource-agnostic CAISO SSP and Capacity Bidding Program (CBP), allowing aggregators to bid in EV capacity like any other resource.

Other Assumptions

- The analysis timeframe included the lifetimes of the bi-directional charger and stationary storage technologies.
- The analysis did not include a customer participation incentive, such as an equipment rebate or enrollment payment, due to the hypothetical nature of a V2H system participating in a DR program such as the SSP, and consequent lack of relevant willingness to accept data from likely participants. While this approach provides a clearer picture, it does produce higher net benefits than a CBA analysis that included a customer participation incentive.
- Taxes were not considered as part of the TRC test because of differential tax rates between private and public entities.
- The 7% after tax weighted average cost of capital (WACC) was the discount rate for all cost tests except the 5% societal discount rate used for the SCT.

4.3.3 Value Stream Definitions

The cost-benefit analysis monetized the value streams listed in Table 11. Whether the value stream is counted as a cost or a benefit depends on the stakeholder perspective as discussed in the subsequent section.

Table 11. Cost-Benefit Analysis Value Streams

Value Stream	Definition
Avoided Capacity	Utility's avoided costs of capacity resulting from storage discharging services in response to DR events
Decreased Energy Supply Costs	Utility's avoided costs of energy resulting from storage discharging services in response to DR events
Customer Bill Reductions	Customer energy and demand bill reductions from load shifted due to responding to DR events
Customer Reliability Improvements	Customer reliability impacts from using storage to carry critical loads through grid outages
Customer Operations and Maintenance (O&M) Costs	Incremental O&M costs of bi-directional charger and stationary storage; customer EV O&M impacts from EV discharging
Customer Capital Costs	Customer one-time upfront costs for installing bi-directional charger and stationary storage
Incentives Paid to Aggregator	Incentive payments paid by utility to the aggregator for providing DR services
Incentives Paid from Aggregator to Customer	Incentives paid by aggregator to customers for responding to DR events
Customer Value of Service Lost (Mobility)	Impact to customer of lost mobility during EV discharge
Customer Transaction Costs (DR)	Transaction costs to the customer associated with participating in Utility DR events
Utility O&M Costs	Utility annual costs for O&M of bi-directional chargers and stationary storage
Utility Capital Costs	Utility one-time upfront costs for installing bi-directional charger and stationary storage
Utility Admin Costs	Utility costs for administering a V2H program

These value streams were categorized into six groups (A-F) based on the calculation methodology used to quantify them. Appendix F provides detailed explanations and data sources for each value stream group.

4.3.4 Relevant Cost Tests and Data Requirements

This analysis assessed cost-effectiveness under the five different tests commonly used in California to determine the value of DERs to customers, utilities, and society, as summarized in Table 12. [90]

[90] California Public Utilities Commission, "California Standard Practice Manual – Economic Analysis of Demand-Side Programs and Projects", *California Public Utilities Commission*, October 2001: http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy_-_Electricity_and_Natural_Gas/CPUC_STANDARD_PRACTICE_MANUAL.pdf

Table 12. Summary of Cost-Effectiveness Tests

Test	Acronym	Summary Approach
Societal Cost Test	SCT	Comparison of society's costs to resource savings and non-cash costs and benefits
Total Resource Cost Test	TRC	Comparison of program administrator and customer costs to utility resource savings
Ratepayer Impact Measure	RIM	Comparison of administrator costs and utility bill reductions to supply-side resource costs
Program Administrator Cost Test	PACT	Comparison of program administrator costs to supply-side resource costs
Participant Cost Test	PCT	Comparison of costs and benefits of the customer installing the technology

The key metric used to assess cost-effectiveness is the ratio of costs to benefits, whereby a ratio of 1 or more indicates that V2H technology is cost-effective. As shown in Table 13, each value stream is treated as a benefit or cost depending on the test used to calculate cost-effectiveness.

Table 13. Value Stream Grouping and Assignments

Group	Value Stream	SCT	TRC	RIM	PACT	PCT
A	Avoided Capacity	Benefit	Benefit	Benefit	Benefit	
B	Decreased Energy Supply Cost	Benefit	Benefit	Benefit	Benefit	
	Customer Bill Reductions			Cost		Benefit
C	Customer Reliability Improvements	Benefit	Benefit			Benefit
D	Customer O&M Costs	Cost	Cost			Cost
	Customer Capital Costs	Cost	Cost			Cost
E	Incentives Paid to Aggregator			Cost	Cost	
	Incentives from Aggregator to Customer					Benefit
	Customer Value of Service Lost (Mobility)	Cost	Cost			Cost
	Customer Transaction Costs (DR)	Cost	Cost			Cost
F	Utility O&M Costs	Cost	Cost	Cost	Cost	
	Utility Capital Costs	Cost	Cost	Cost	Cost	
	Utility Admin Costs	Cost	Cost	Cost	Cost	

Appendix F provides detailed explanations of the calculation methodology and data sources used to quantify each value stream group for each cost test.

4.4 Task 4: Cost-Benefit Analysis Results

The V2H Cost-Benefit Analysis achieved the project objective of estimating the value of a V2H system to customers, the utility, and society by monetizing the net benefits of bi-directional V2H charging infrastructure and stationary storage to provide a net new comparison. Analyzing the three V2H system configurations discussed in Section 4.3.1 from the customer, utility, and societal perspectives under demand response and outage conditions produced the following key findings based on the detailed results contained in this section:

- Using an EV to respond to a demand response event **without a participation incentive** is cost-effective from a program administrator cost test perspective when considering the demand response capacity benefits to a program administrator.
- Several key secondary drivers may lead to additional cost-effective scenarios in the future, including declining overall technology costs and stacking additional storage value streams.
- V2H system with solar PV and stationary storage provides significant resiliency benefits to the customer in the case of sustained outages, through it is not clear whether the additional resiliency hours for the site owner translate into value for the utility or society.

Based on the cost-benefit analysis findings, PG&E identified the following areas for further investigation discussed in this section:

- Investigate optimal system configurations from all cost test perspectives for all system configurations (EV, SS, EV+SS).
- Investigate value of resiliency to the customer, utility, and society during periods of long sustained outages.
- Investigate load distribution during periods of long sustained outages.
- Investigate opportunities to minimize upfront capital costs to make V2H cost-effective from a customer perspective.

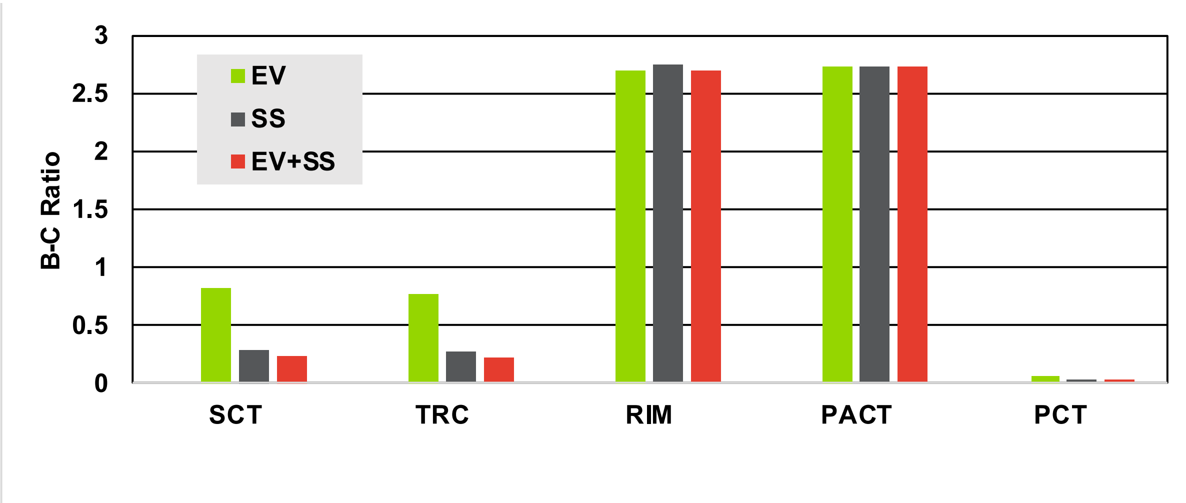
This section details the key findings, conclusions, and areas for further investigation flowing from the cost-benefit analysis.

4.4.1 Key Findings

All Cost Tests – Cost-Benefit Ratio Results

As shown in Figure 12, the configurations are cost-effective for demand response participation from the ratepayer and utility (program administrator) perspectives, but not from the customer or societal perspectives.

Figure 12. Summary of Cost-Effectiveness Measured by Cost-Benefit Ratios



These results produce the following key findings:

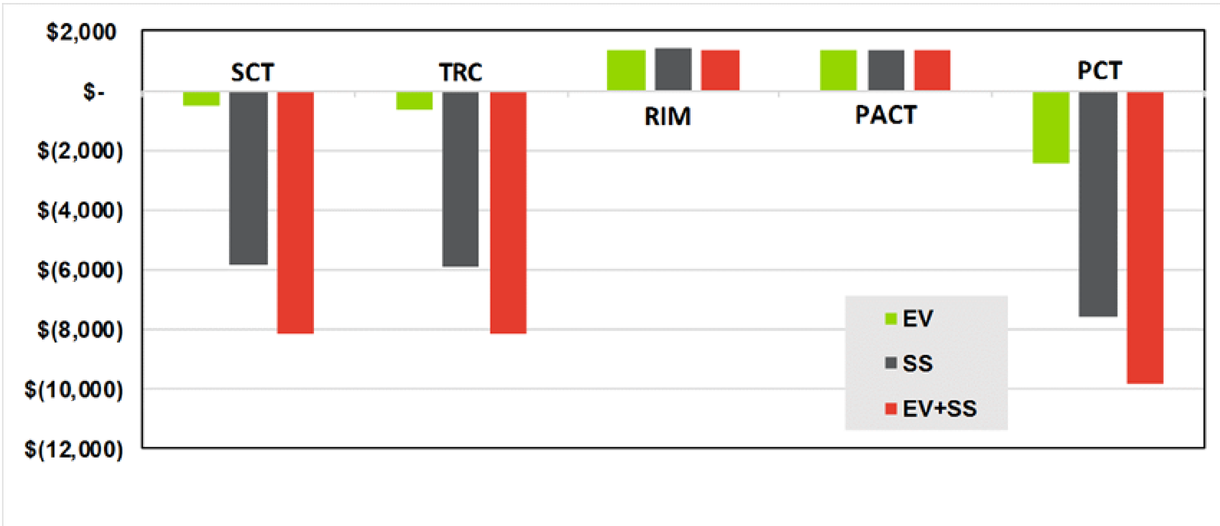
- Ratepayer funds spent on administering the DR program are justified by deferred or avoided capacity and energy supply costs that would otherwise be incurred. These perspectives are represented by the RIM test and the PACT results, respectively, in the figure.
- The configurations are not cost-effective from the perspective of all parties. This means that costs incurred by all involved parties, including the utility and customer, are not currently justified by deferred or avoided capacity and energy supply costs, along with any customer reliability improvements. This perspective is represented by the SCT and TRC test results in the figure.
- The difference between the SCT and TRC in this study is the discount rate used in the present value calculations, whereby the discount rate used for the SCT is lower than that used for the TRC. This lower discount rate reflects reduced investment risk due to long-term benefits to society.
- Finally, the configurations are also not cost-effective from the customer perspective, meaning that the upfront capital cost incurred by the customer is not justified by any bill reductions, customer incentives or reliability improvements they would gain. This perspective is represented by the PCT results in the figure.

In summary, upfront customer capital cost is the largest barrier to cost-effectiveness, which is why all tests that consider the customer perspective produce a cost-benefit ratio of less than 1. The cost-effective result for participation in a DR program under the RIM and PACT tests rests on the assumption that a small incentive payment would be sufficient to garner customer participation in the program.

All Cost Tests – Net Benefits Results

In terms of stakeholder net benefits, as shown in Figure 13, the EV-only scenario produces net-benefits from the utility (program administrator) perspective, almost produces net benefits from the societal perspective, but does not produce net benefits from the customer perspective.

Figure 13. Summary of Cost-Effectiveness Measured by Net Benefits



These results produce the following key findings:

- The EV-only scenario is almost cost-effective from the societal perspective, represented by the under the SCT and TRC test results, due to the significant capacity benefits and low capital cost of bi-directional charging relative to the cost of stationary storage.
- Ratepayers and the utility see positive net benefits when the customer bears the capital costs of the V2H system and participates in a DR program, represented by the RIM test and PACT results in the figure, as the utility does not incur any capital costs to administer the DR program.
- Finally, as previously mentioned, customers see negative net benefits, represented by the PCT results in the figure, as the bill reductions, incentives reliability improvements gained are not sufficient to recover the capital costs.

Collectively, the previous two figures demonstrate that there is very little difference in the cost-effectiveness results between the SCT and TRC, as well as the RIM and PACT. This is because the only difference between the SCT and TRC is the discount rate used in the present value calculations, while customer bill reductions, which are minimal, is the only additional value stream in the RIM relative to the PACT.

Consequently, for simplicity, detailed results for only the TRC, PACT, and PCT are discussed throughout the rest of this subsection. Table 14 provides a preview of these results by summarizing the present value of benefits, costs, net benefits and corresponding benefit-cost ratios for all three configurations under these three key tests.

Table 14. Summary of Cost-Effectiveness Results under TRC, PACT and PCT Tests for all Configurations

Cost-Effectiveness Metric	Electric Vehicle (EV) Only	Stationary Storage (SS) Only	Electric Vehicle + Stationary Storage (EV + SS)
Total Resource Cost (TRC) Test			
Present Value of Benefits	$2,241	$2,241	$2,241
Present Value of Costs	$2,889	$8,113	$10,401
Present Value of Net Benefits	-$648	-$5,872	-$8,160
Benefit-Cost Ratio	0.78	0.28	0.22
Program Administrator Cost Test (PACT)			
Present Value of Benefits	$2,193	$2,193	$2,193
Present Value of Costs	$804	$804	$804
Present Value of Net Benefits	$1,389	$1,389	$1,389
Benefit-Cost Ratio	2.73	2.73	2.73
Participant Cost Test (PCT)			
Present Value of Benefits	$161	$243	$258
Present Value of Costs	$2,593	$7,817	$10,105
Present Value of Net Benefits	-$2,432	-$7,574	-$9,846
Benefit-Cost Ratio	0.06	0.03	0.03

Total Resource Cost (TRC) Results

The following three figures show the breakdown of benefits and costs for each configuration under the TRC test, which represents the perspective of all parties, including the utility and customer. For all configurations, customer capital costs are the main cost, while avoided capacity and energy supply are the primary benefits.

Figure 14. Costs and Benefits under TRC Test for EV-Only Configuration

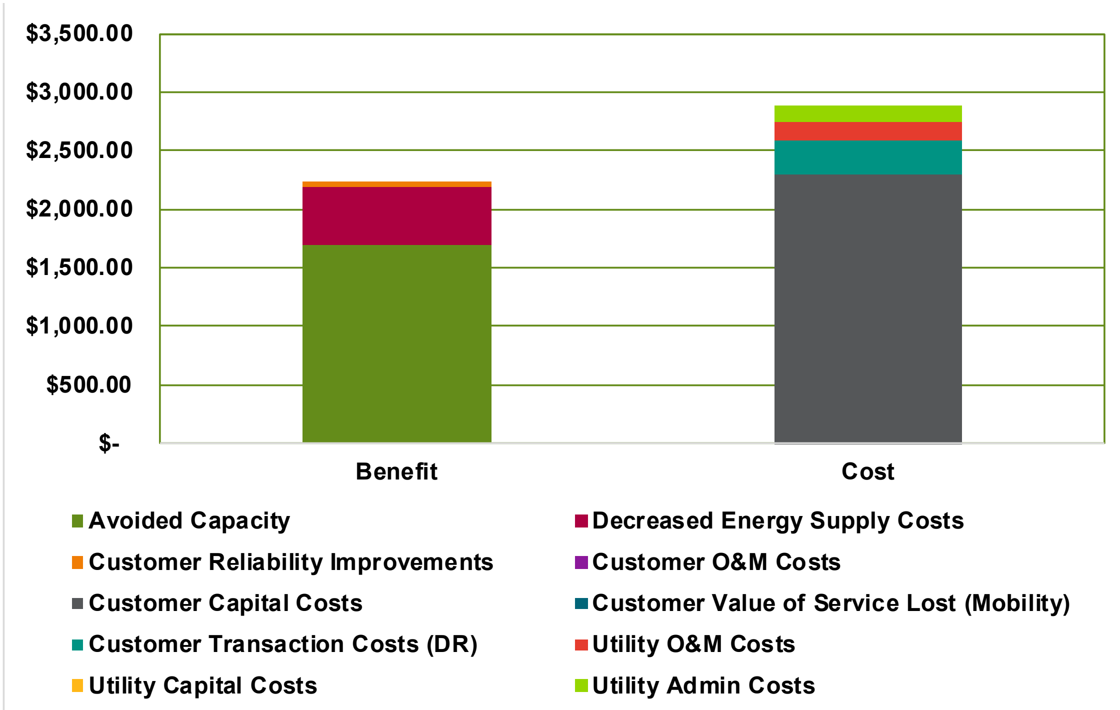


Figure 15. Costs and Benefits under TRC Test for Stationary Storage-Only Configuration

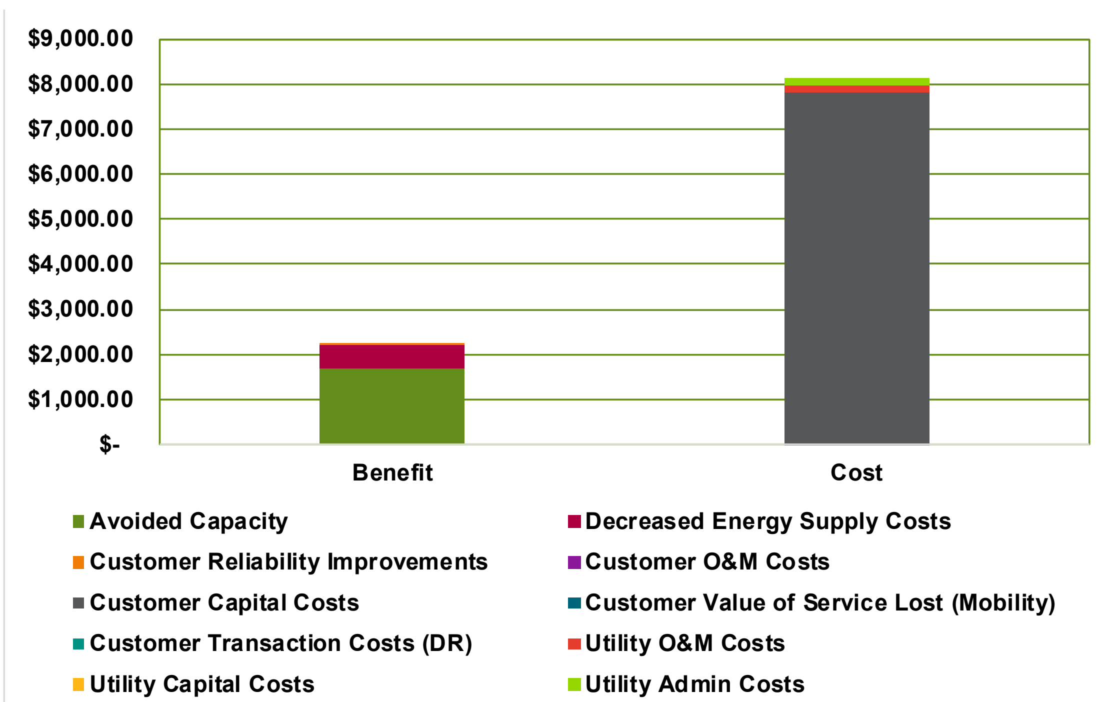
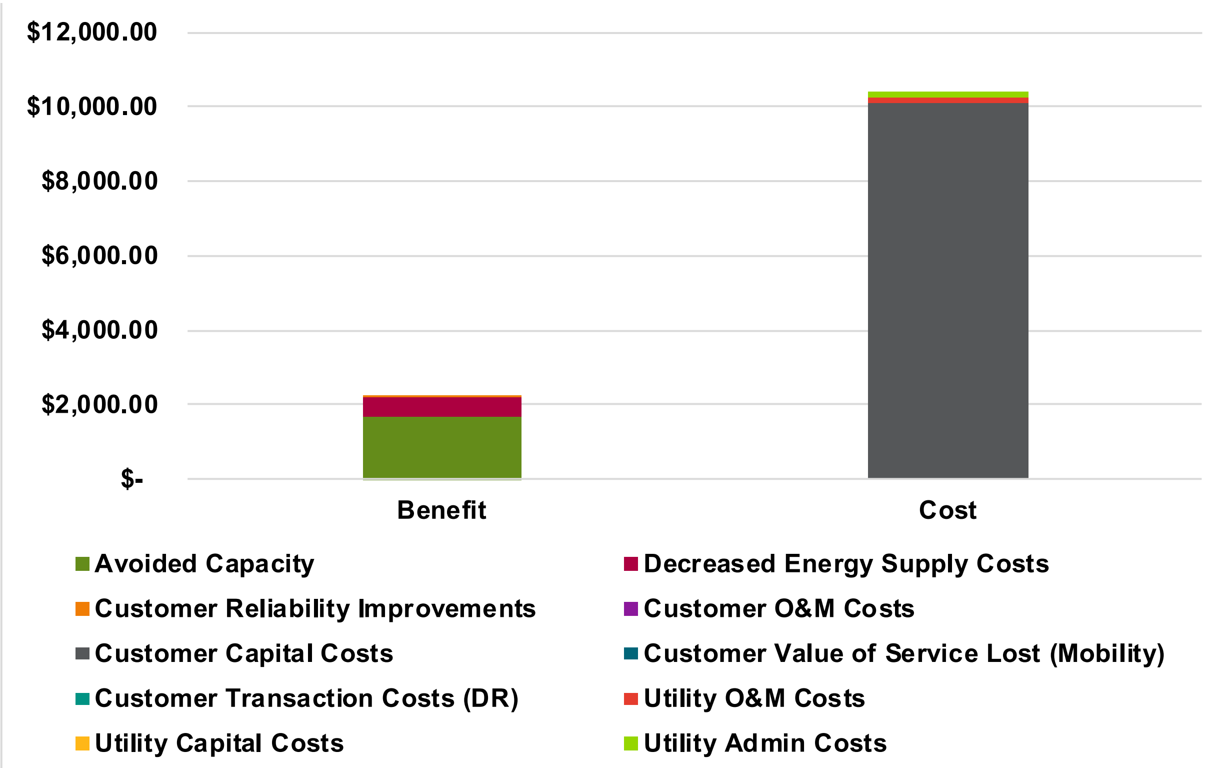
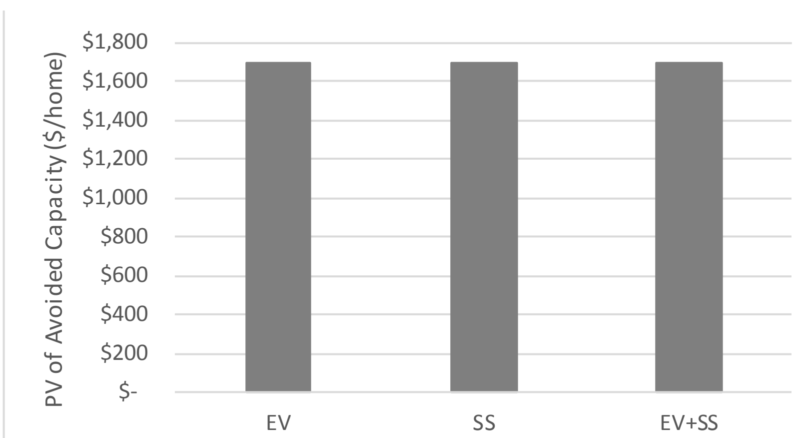


Figure 16. Costs and Benefits under TRC Test for EV and Stationary Storage Combination Configuration



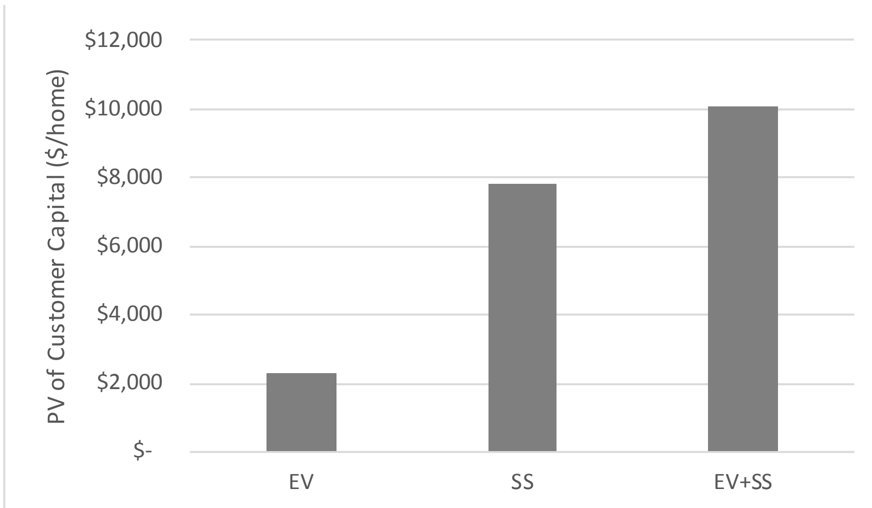
Because each system only discharges to the critical panel, which includes HVAC, plug loads, and refrigeration net of PV, the load available for offset is approximately 4 kWh during the average DR event. This is below the maximum capacity of each battery, which is assumed to be 14 kWh and 50 kWh for the stationary storage and EV, respectively. As shown in Figure 17, this results in equivalent capacity benefits across the configurations.

Figure 17. Avoided Capacity Benefits under the TRC Test by Configuration



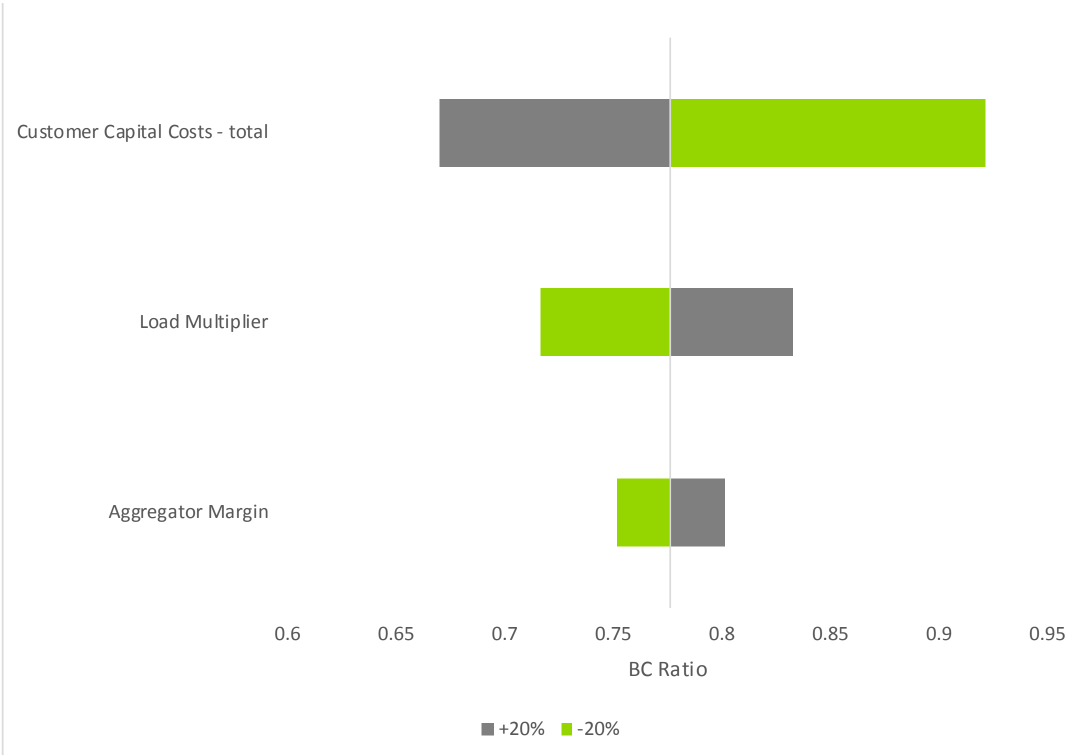
Although the benefits do not vary across the configurations, the technology cost differences are significant, as shown in Figure 18. This drives the variance in the net benefits and cost-benefit ratios for any test that considers the perspective of customer, who bears the upfront capital cost of the technology.

Figure 18. Customer Costs under the TRC Test by Configuration



This analysis also identified the most sensitive inputs to the TRC test's cost-benefit ratio. As shown in Figure 19, customer capital cost, the amount of load available on the critical panel, and the aggregator margin, which dictates the amount of incentives the customer receives, are the top drivers of cost-effectiveness under the TRC test for the EV-only configuration. The load available on the critical panel directly affects the magnitude of the benefits, as greater load means a higher capacity benefit during DR events. Although incentives are treated as a transfer value stream under the TRC test, the cost-benefit ratio is sensitive to the aggregator margin because it affects the participant transaction cost, or hassle that the customer incurs.

Figure 19. Tornado Chart [91] under TRC Test for EV-Only Configuration



Program Administrator Cost Test (PACT) Results

The next three figures show the breakdown of benefits and costs for each configuration under the PACT, which represents the perspective of the DR program administrator or utility. For all configurations, few utility costs due to the customer bearing the capital costs, and strong capacity benefits yield positive net benefits for the DR program administrator.

[91] A tornado chart is a tool used to depict the sensitivity of a result to changes in selected variables of the cost-benefit analysis.

Figure 20. Costs and Benefits under PACT for EV-Only Configuration

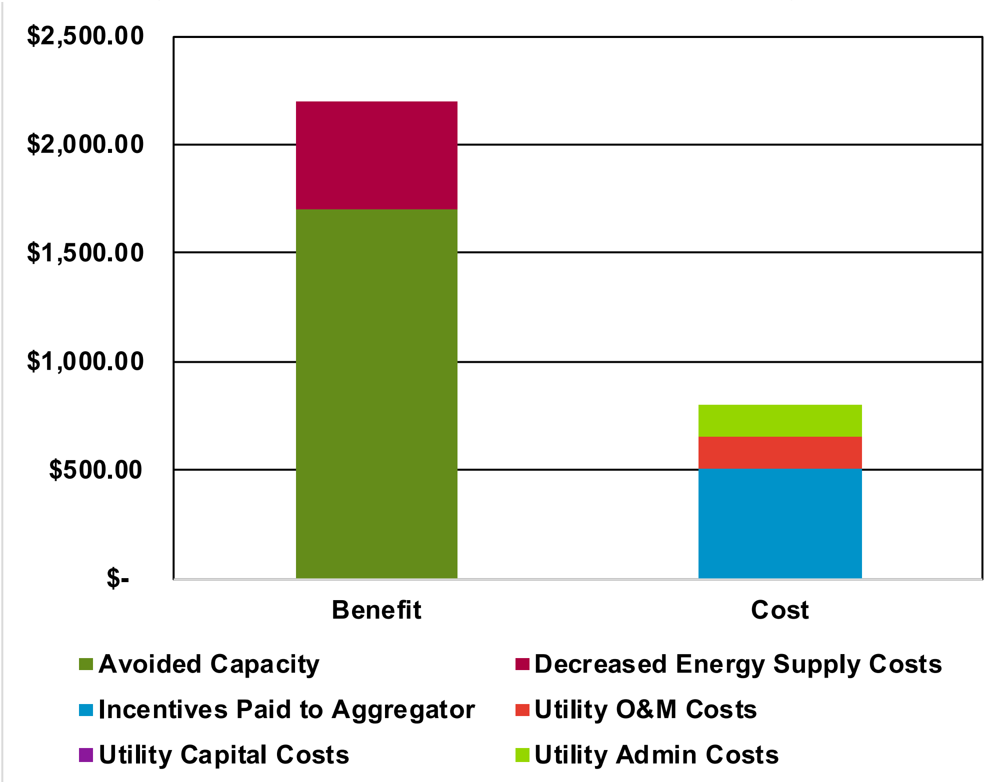


Figure 21. Costs and Benefits under PACT for Stationary Storage-Only Configuration

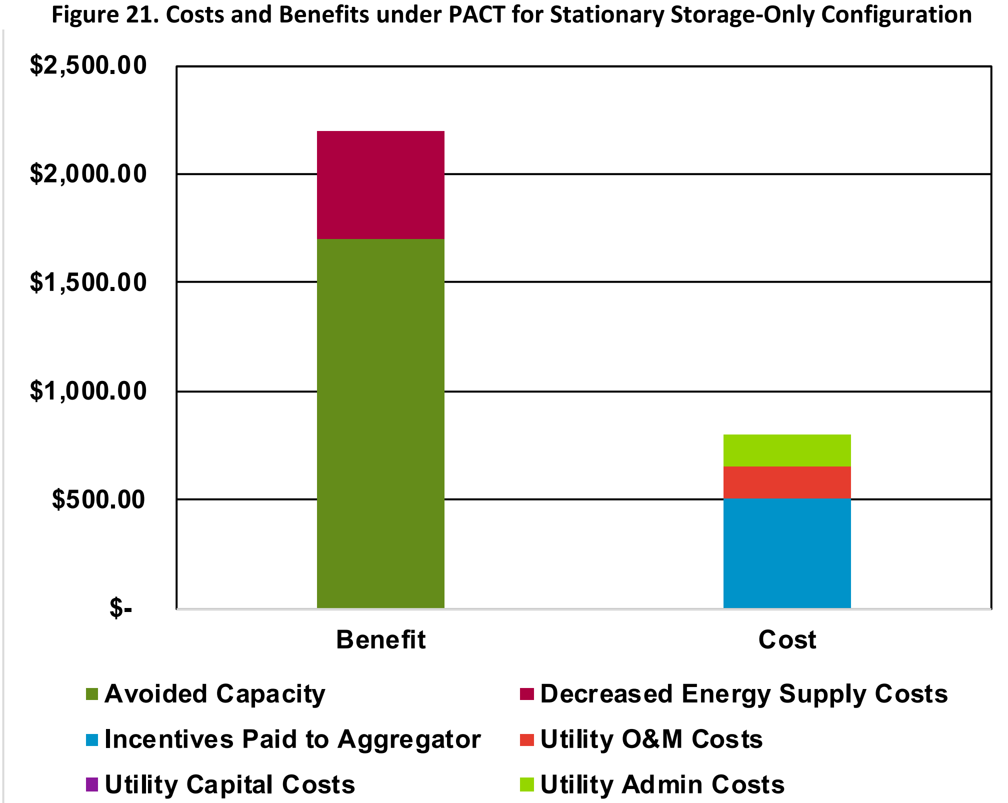
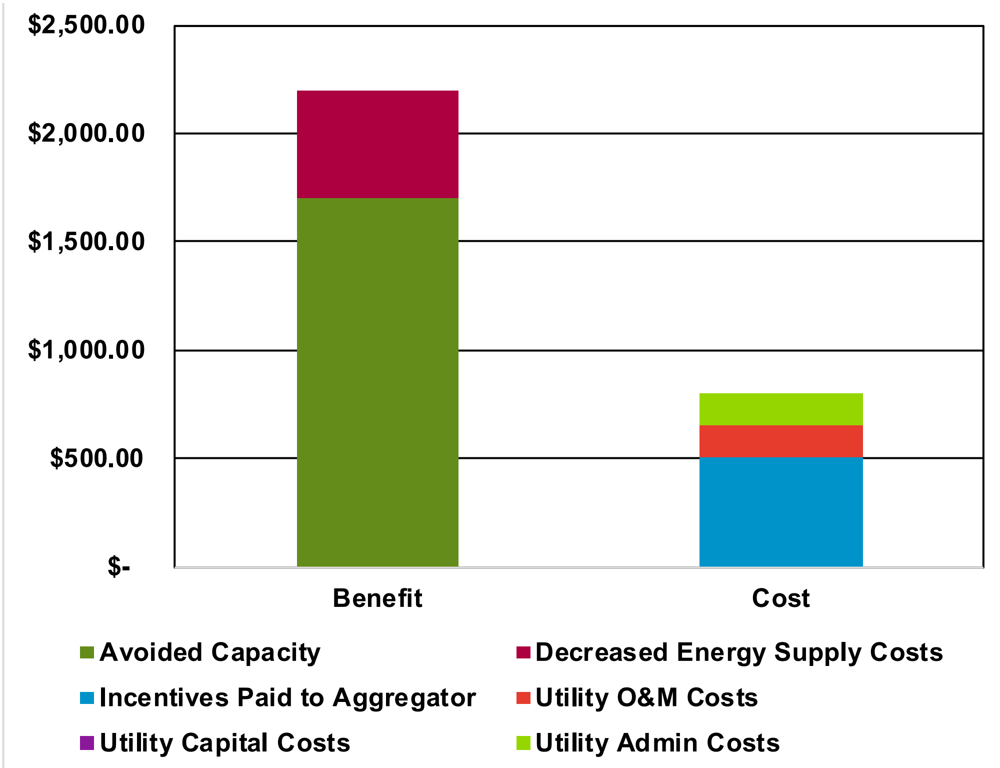
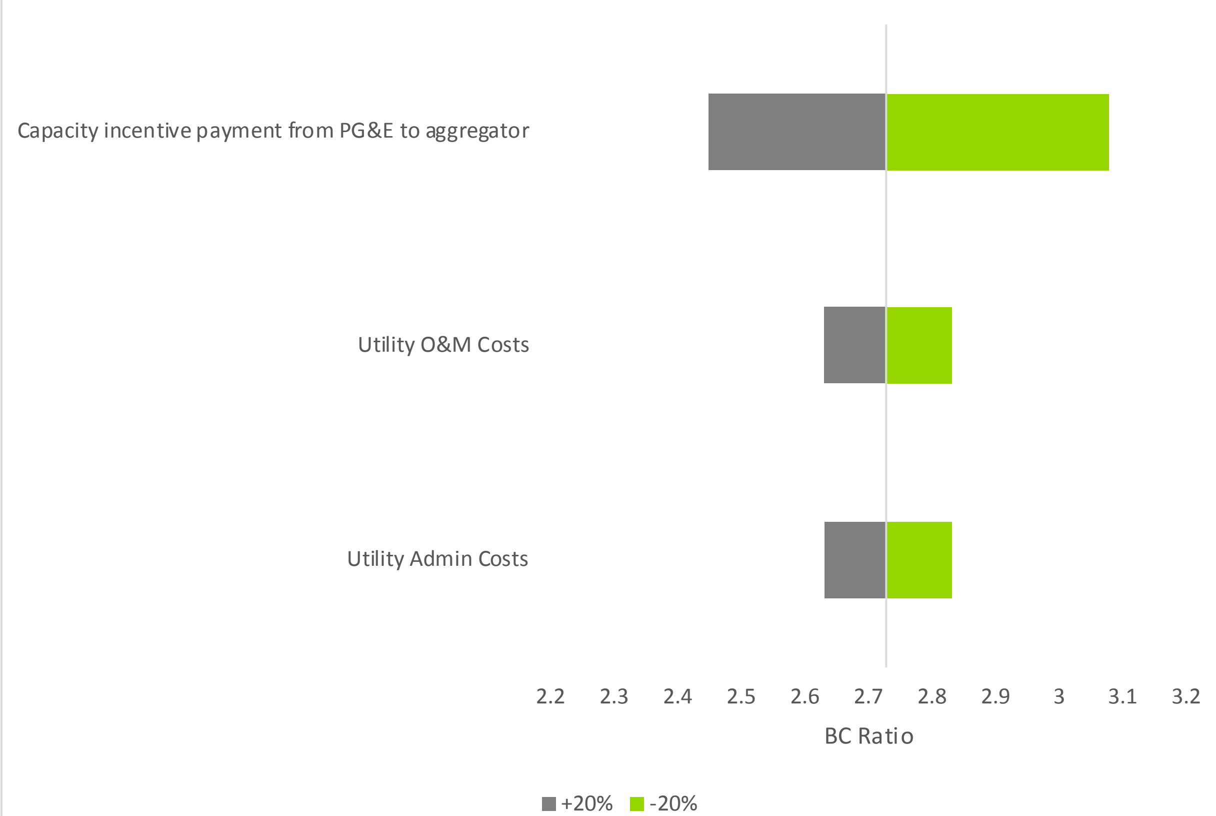


Figure 22. Costs and Benefits under PACT for EV and Stationary Storage Combination Configuration



This analysis also identified the most sensitive inputs to the PACT's cost-benefit ratio. As shown in Figure 23, incentive payments, administrative, and O&M costs are the top drivers of cost-effectiveness under the PACT for the EV-only configuration. Note that the cost-benefit ratio is always above 1.

Figure 23. Tornado Chart under PACT for EV-Only Configuration



Participant Cost Test (PCT) Results

The following three figures show the breakdown of benefits and costs for each configuration under the PCT, which represents the customer perspective. For all configurations, high capital costs and relatively few incentives that reach the customer yield negative net benefits for the customer.

Figure 24. Costs and Benefits under PCT for EV-Only Configuration

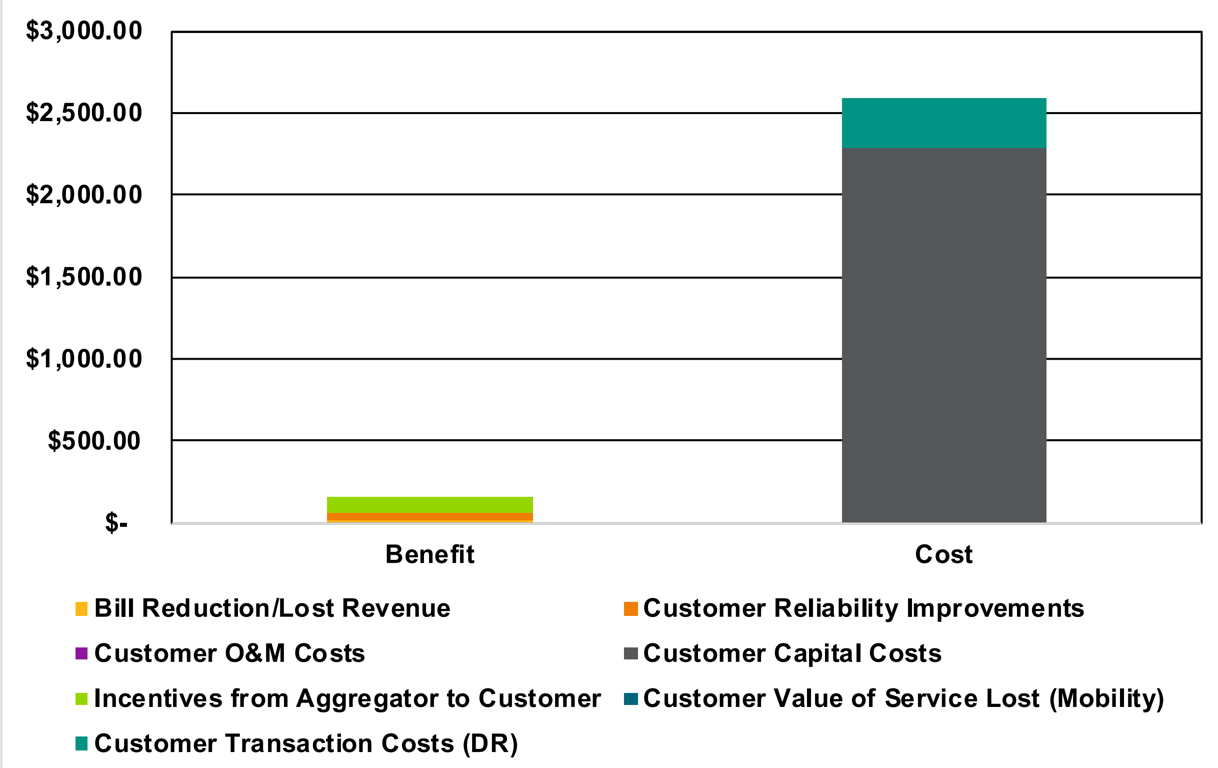


Figure 25. Costs and Benefits under PCT for Stationary Storage-Only Configuration

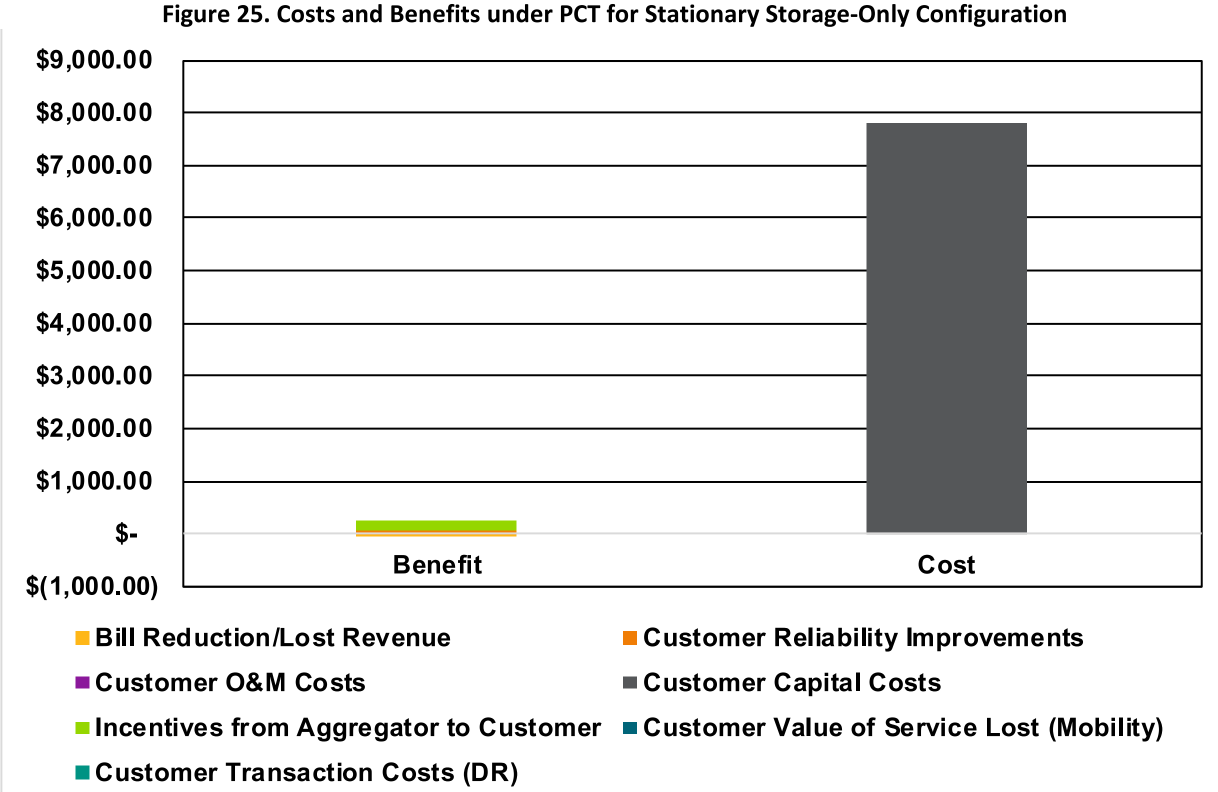
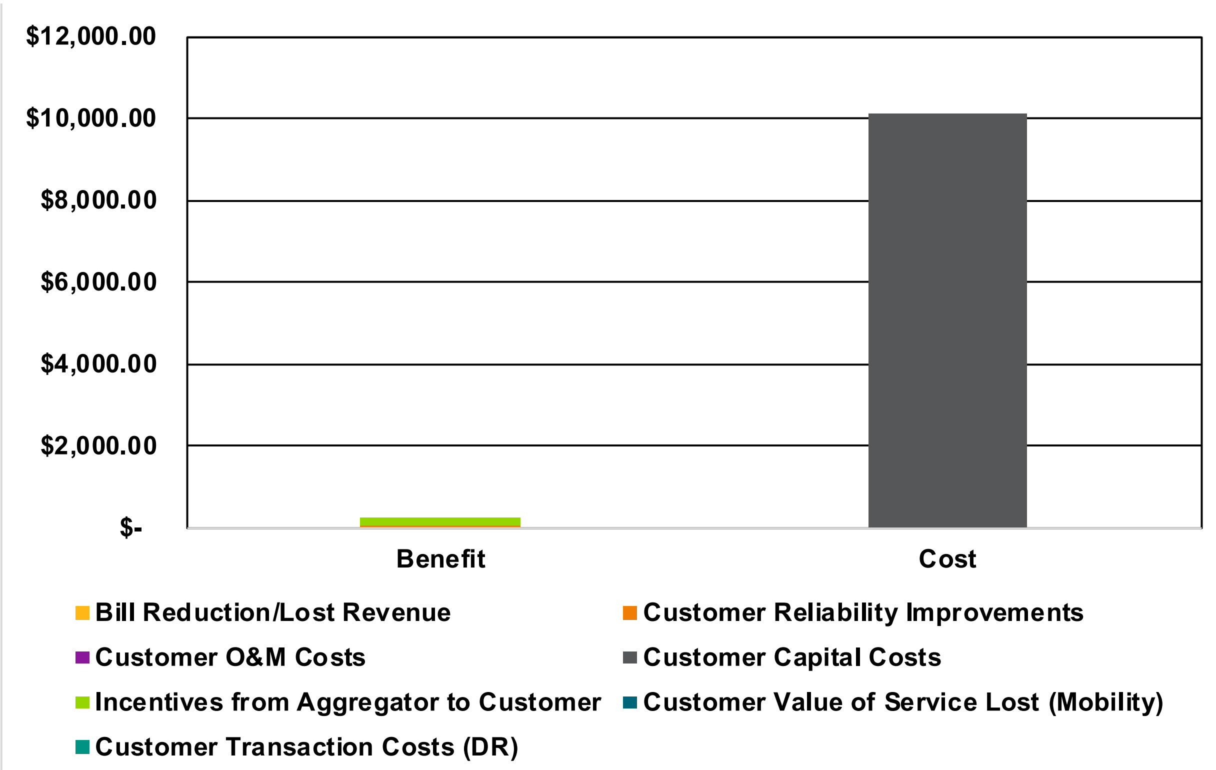
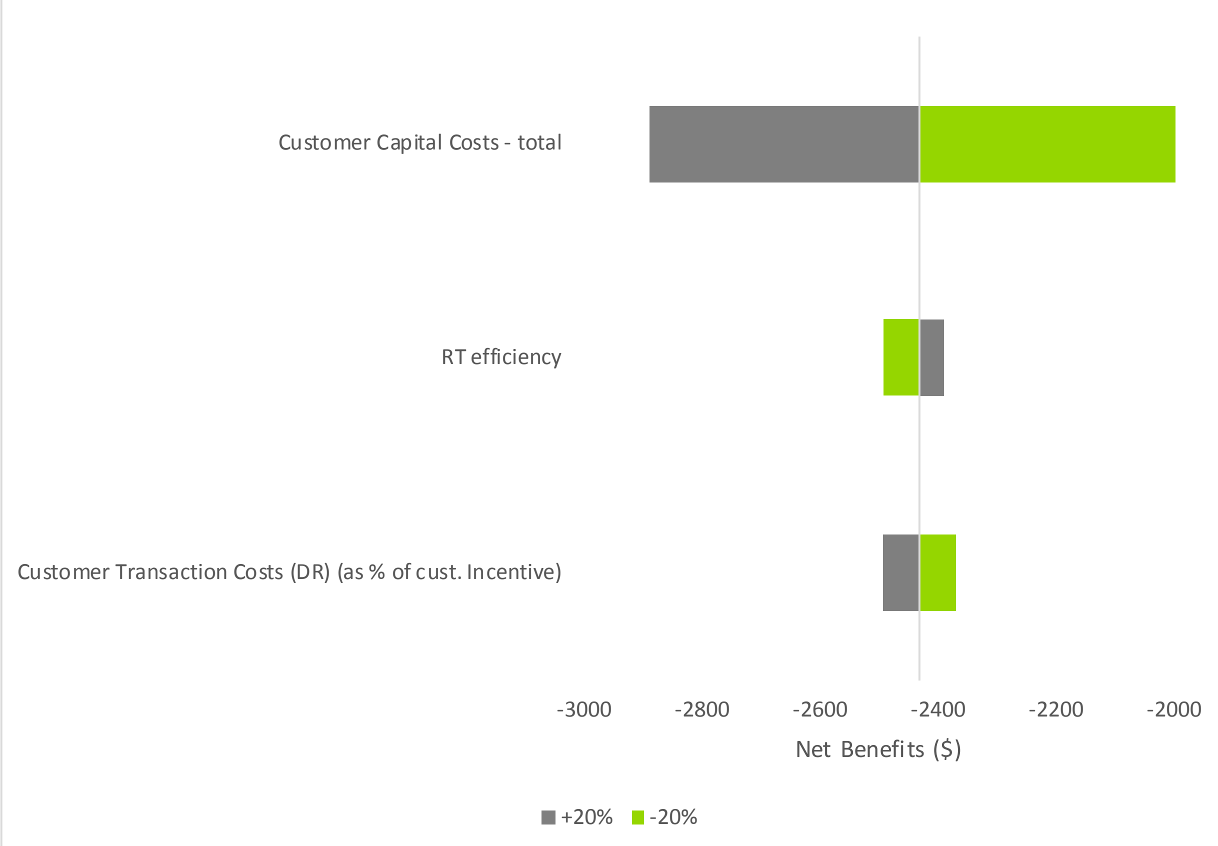


Figure 26. Costs and Benefits under PCT for EV and Stationary Storage Combination Configuration



This analysis also identified the most sensitive inputs to the PCT's net benefits. Net benefits are shown on the x-axis instead of the cost-benefit ratio for the PCT because the sensitivity analysis revealed that the cost-benefit ratio is not sensitive to most inputs due to high capital costs in the denominator. As shown in Figure 27, customer capital cost, the bi-directional charger's roundtrip efficiency, and the participants transaction costs—or hassle—are the top drivers of cost-effectiveness under the PCT for the EV-only configuration. Although not shown in Figure 27, both the aggregator margin (percentage of the incentive payments from PG&E) and the customer A factor (percentage of events the customer is able to participate in) directly influence the customer's benefit from incentive payments. However, the customer capital cost is a more significant driver of cost-effectiveness.

Figure 27. Tornado Chart under PCT for EV-Only Configuration



Additional Considerations of Cost-Effectiveness

The cost-effectiveness tests above assumed that monetary incentives for customer participation were in line with existing demand response programs. The project investigated what additional incentive level might need to be offered to spur customer adoption and the impact of that on the cost-effectiveness results. Additionally, the considered other circumstance that would materially affect the cost-effectiveness results.

In the customer survey PG&E conducted, respondents were asked what they thought was a *reasonable amount* and what was *too expensive* for a V2H system. The highest price that any respondent thought was *reasonable* was just under $2500, at that price level all but 30% of respondents thought a V2H system would be *too expensive* suggests. With a V2H system estimated to a customer $4500 (total installed cost), these results suggest that the minimum incentive level that would result in customer interest would be $2000. At this incentive level 30% of the survey population would not think the technology is too expensive (see Appendix G) – however it is important to note that actual adoption % would likely be lower, just thinking something is not too expensive does not necessarily translate to a customer thinking they need it and adopting it.

When this minimum incentive level of $2000 is incorporated into the cost-benefit analysis, the net benefits to the customer (PCT) improves but does not become positive, net benefits under all cost-effectiveness tests remain negative (see Figure 29). The benefit-to-cost ratio to the utility and ratepayers (PACT and RIM tests) goes down when $2000 of benefit is transferred to the customer as an incentive and the customers benefits go up (PCT). However, under this scenario of minimum incentive level (based on current customer survey results), the benefit-cost ratios under all of the cost-effectiveness tests are below 1 (see Figure 28).

Figure 28. Cost-Benefit Ratios Summary including EV with Incentive Scenario

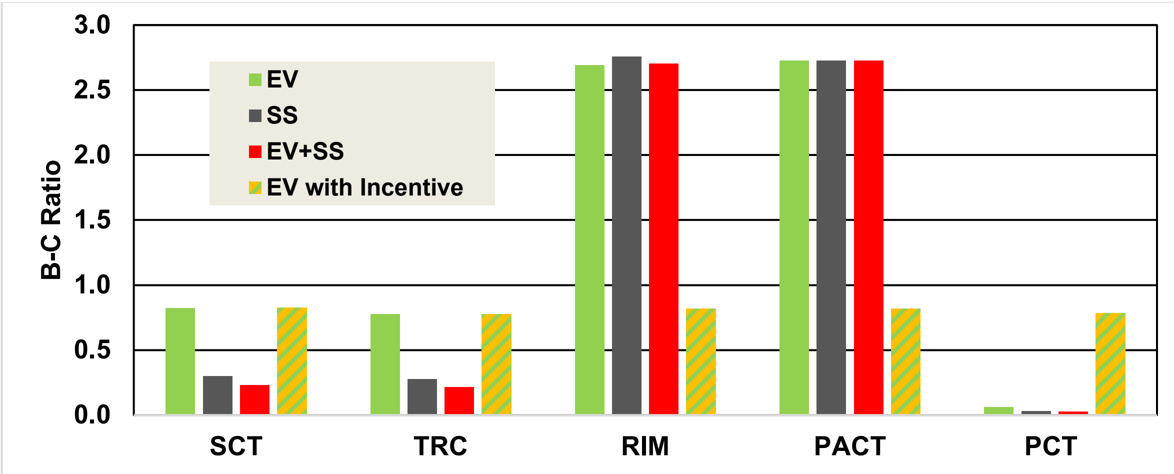
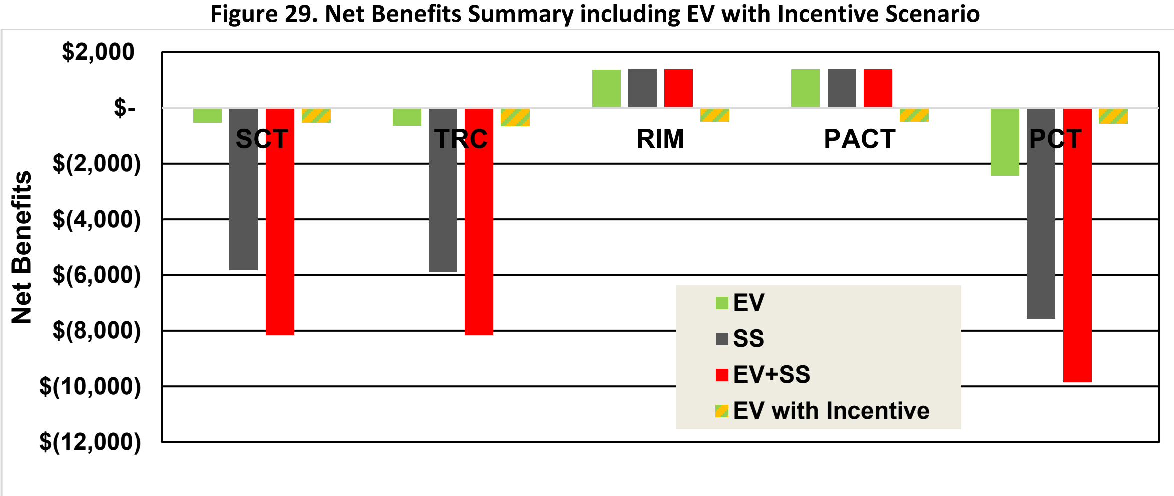


Figure 29. Net Benefits Summary including EV with Incentive Scenario



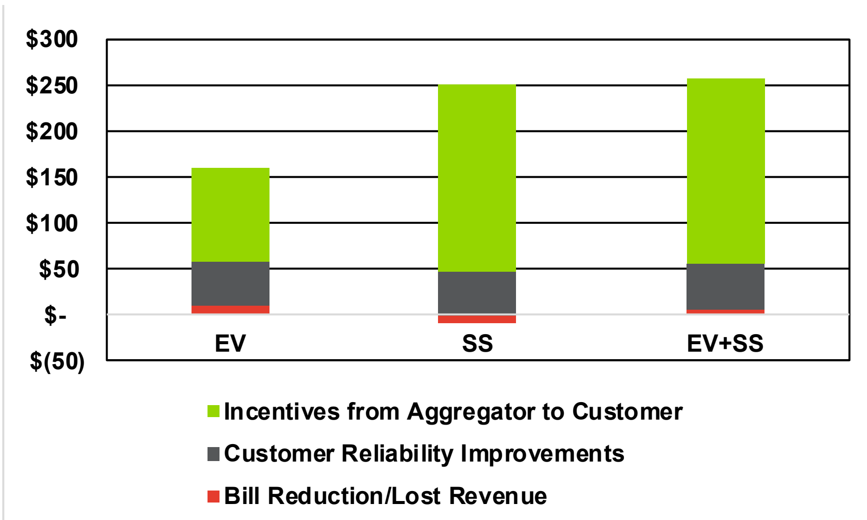
Without additional participation incentives, the EV-only scenario could be cost-effective for the TRC test and PCT under the following circumstances:

- The TRC EV-only scenario is cost-effective if customer capital cost is reduced by about 25% or the home has 1.65 times the load of the test home modeled with the Snapshot Efficiency Tool.
- The PCT EV-only scenario is cost-effective if the customer A factor, which represents the availability of EV is to respond to a DR event, is 100% and the customer capital cost is reduced by 110%. This means that the customer's vehicle would have to be available for discharge any and every time a DR event is called, and the bi-directional charger would have to be free-of-charge to the customer, with some added incentives.

The benefits to the customer are small relative to the costs, with some important considerations for future investigation. Figure 30 compares the benefits across technical system configurations. The stationary system is always available for event participation and, therefore, yields greater benefits.

Yet, lower roundtrip efficiency relative to the EV battery increases bills slightly.[92][93] The base case of the analysis assumes that the EV is available for event participation half of the time (a 50% customer A factor). EV benefits equal stationary storage benefits at a customer A factor of 85%, meaning that the EV needs to be available and parked in the garage with sufficient charge to participate in an event 85% of the time to equal the benefits provided by stationary storage. If the EV is available 100% of the time (*e.g.*, an exuberant customer is careful to participate in every DR event) then the benefits of the EV are greater than benefits from the stationary storage configuration due to the lower roundtrip efficiency relative to the EV.

Figure 30. Present Value of Homeowner Benefits



As discussed in Section 4.2 , the system configuration only allows the battery to serve the critical panel load net of PV generation. The load on the critical panel available for DR dispatch is relatively small, at only 18% of the effective kWh capacity of the EV battery and 31% of the effective kWh capacity of the stationary storage battery. If instead a customer was using a V2G setup this could allow the storage to fully discharge to capture greater benefits from DR participation. Furthermore, the analysis only considered the quantifiable benefits associated with V2H functionality (participating in the SSP/CBP DR program and carrying critical loads through outages (*e.g.*, the DR and outage scenarios). Alternatively, V2G functionality would enable daily customer load shifting in response to TOU rates or demand charges, or compensation for grid services provided by storage are potential benefits that were not considered and would benefit from further investigation. A V2G system that captures these other benefits may lead to a significant increase in battery cycling frequency, which could also lead to increased O&M costs and shorter battery lifetimes.

PG&E performed an analysis to assess what the magnitude of additional benefits would need to be for the PCT to yield net benefits. Table 15 shows that, in the EV case, the customer would need to earn an additional $346 annually from any other benefits not explicitly considered in this analysis to achieve net benefits, which could be achieved by TOU load shifting, for example. However, given that several of these benefits involve V2G functionality they could only be realized in addition to V2H benefits by a

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[92] Elpiniki Apostolaki-Iosifidou et al., “Measurement of Power Loss During Electric Vehicle Charging and Discharging,” *Science Direct,* no. 127 (2017): 730-742, http://www.sciencedirect.com/science/article/pii/S0360544217303730.

[93] Tesla, “Powerwall,” *Tesla,* 2017, https://www.tesla.com/powerwall.

combined V2H and V2G system which does not yet exist and likely would entail additional equipment costs.

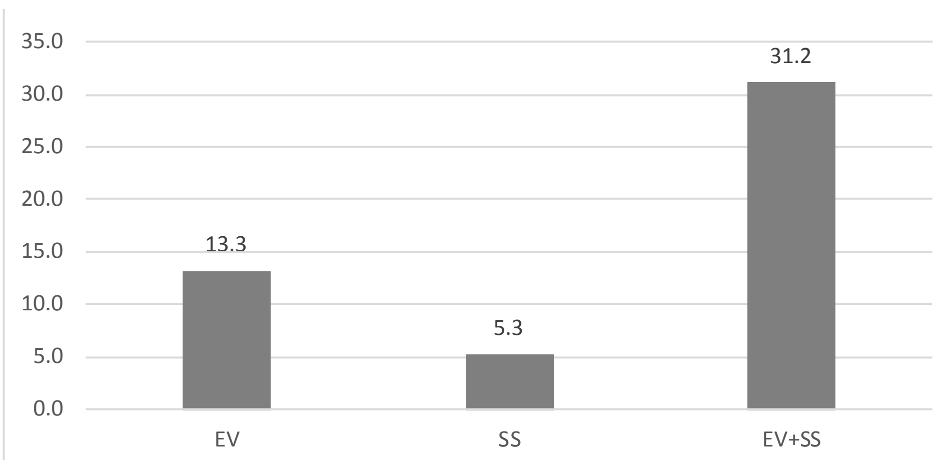
Table 15. Additional Value Necessary for the PCT Cost-Benefit Ratio to be Greater than 1.0

	Additional Nominal Value ($/year)	Present Value over Lifetime of Tech (2017 $)
EV	$346	$2,433
SS	$1,078	$7,575
EV + SS	$1,402	$9,847

Sustained Outage Scenario

The incremental value of the EV when added to stationary storage is significant in long-term outage scenarios, though the system configuration tested was representative of a very limited scenario of the consumer's home functioning from the critical panel. During a typical summer outage, the EV adds approximately 20 days of additional critical panel service over just the stationary storage. Figure 31 shows the duration for the combined scenario is more than the sum of the two independent technologies due to the combined greater capacity to absorb solar PV generation.

Figure 31. Days of Resiliency by Scenario for Summer Outage



As depicted in Table 16, the resiliency time is highly sensitive to the timing of the outage due to annual variability in solar PV generation. Further, the resiliency time is sensitive to the SS battery SOC at the time of the outage. Notably, as identified in Test 70 (Section 4.2.3), if the SS or EV battery SOC reached 100% while islanded from the grid, the PV would trip, thereby reducing resiliency time without manual intervention on the part of the homeowner. This manual intervention would be needed to re-integrate PV once battery SOC had reduced enough to allow absorption of excess PV generation. However, in peak PV generation season, the SOC at the time of the outage does not affect the days of resiliency, as the PV is able to serve all the critical load and fully charge the EV during the spring months. Notably, this resiliency benefit will need to be balanced with mobility needs. Also, it is not clear whether the additional resiliency hours for the site owner translate into value for the utility or society.

Table 16. Days of Resiliency for Each Technical Configuration, Considering Outages Starting in Different Seasons with Different EV SOCs

EV SOC at Time of Outage ↓	Scenario → Outage Start Day ↓	Days of Resiliency		
		EV	SS	EV+SS
50%	Jan 1st	5.8	1.8	8.0
	March 31st	105.2	48.9	119.3
	July 27th	13.3	5.3	31.2
100%	Jan 1st	11.4	1.8	13.2
	Mar 31st	105.2	48.9	119.3
	July 27th	34.1	5.3	38.0

4.4.2 Conclusions

In service of the EPIC Program Charter, PG&E's EPIC 2.03b sought to demonstrate new and novel V2H technology applications and estimate ratepayer benefits associated with these applications. Addressing the net new V2H testing questions was key to the testing and analysis carried out during this project. Evidence from test results suggests that an EV-only V2H system can provide hard islanding and DR functionality. An EV-only V2H system can provide greater net benefits to the customer and utility than stationary storage, though not cost-effectively for the customer. The system is only cost-effective from a PACT perspective if the customer bears the equipment capital costs; a finding that is problematic relative to the customer survey results that found customers' willingness to pay for a V2H system is notably lower than the estimated system cost (see Appendix G . The analysis also indicates that a V2H system with solar PV and stationary storage provides significant, compounded resiliency benefits in the case of sustained outages.

The cost-benefit analysis quantitatively demonstrates how much the value of V2H varies significantly depending on the stakeholder viewpoint. The primary driver of the net benefits is the allocation of equipment capital costs among stakeholders. Several key secondary drivers may lead to cost-effective potential future scenarios for the customer such as declining overall technology costs and monetizing additional storage value streams (*e.g.*, customer-driven load shifting, V2G system configuration, and ancillary services). In the future, declining costs of the enabling technology and the potential for additional value streams, might make it cost-effective from the participant's perspective. Future analysis should consider the O&M and battery lifetime costs of enabling these value streams.

4.4.3 Areas for Further Investigation

Based on the results of the cost-benefit analysis and literature review, PG&E sees the need for all system configurations (EV, SS, EV+SS) to be further investigated to determine optimal system configurations from all cost test perspectives and to understand the incremental value of the following:

- Connecting both the main and critical panels to be served by the PV and storage combinations
- Developing V2G and storage-to-grid ability to cost-effectively participate in DR event capacity offerings
- Understanding the ability to monetize benefits incremental to the DR/outage benefits considered in this analysis (*e.g.*, customer-driven load shifting opportunities) as well as the costs (O&M and battery lifetime reductions) associated with providing those benefits

Further investigation is needed to understand the value of resiliency to the customer, utility and society, as well as what happens to loads during periods of long sustained outages. Questions of particular importance include:

- How does a customer's willingness to pay for resiliency relate to utility and societal benefits, if any, during periods of long sustained outages?
- What conservation behaviors can be expected during long-term outages? In other words, how would the customer's load change in a multiday outage? With the right mix of technology and conservation behavior, could the customer island indefinitely?

From a customer perspective, further investigation is needed to understand the solar PV system size, vehicle type, stationary storage, and home load parameters that may be combined to create a least-cost ZNE home with unlimited resiliency capabilities. Potential exists to add EVs to the Snapshot Efficiency Tool to maximize its value, while benefiting from the cost synergies of leveraging a preexisting ratepayer-funded research tool.

When considering utility and regulatory perspectives, further investigation is required on the network effect of many customers with bi-directional charging capabilities and the system benefits of this network. Also, it is not clear whether the additional resiliency hours for the site owner translate into value for the utility or society.

Overall, the cost-benefit analysis and framework development led PG&E to several significant and novel insights related to the relevant perspectives, technical configurations, and DR/outage conditions considered. Results indicate that, although the technology is not currently cost-effective from most perspectives, there are significant exciting directions for future investigation and development related to V2H and V2G technology.

Consequently, the primary recommendation of this EPIC project is to plan and execute a field test of V2G/V2H technology with a market actor partner in PG&E's CAISO SSP program. The effort would seek to test optimal system configurations while ascertaining actual interconnection, performance, and customer participation data. The investigation would further test the value of resiliency to the customer over short and long-term outage durations. In undertaking these areas of investigation, this effort would further inform the viability of commercializing V2G/V2H technology and help to understand its potential benefits for PG&E customers and the utility from all cost test perspectives.

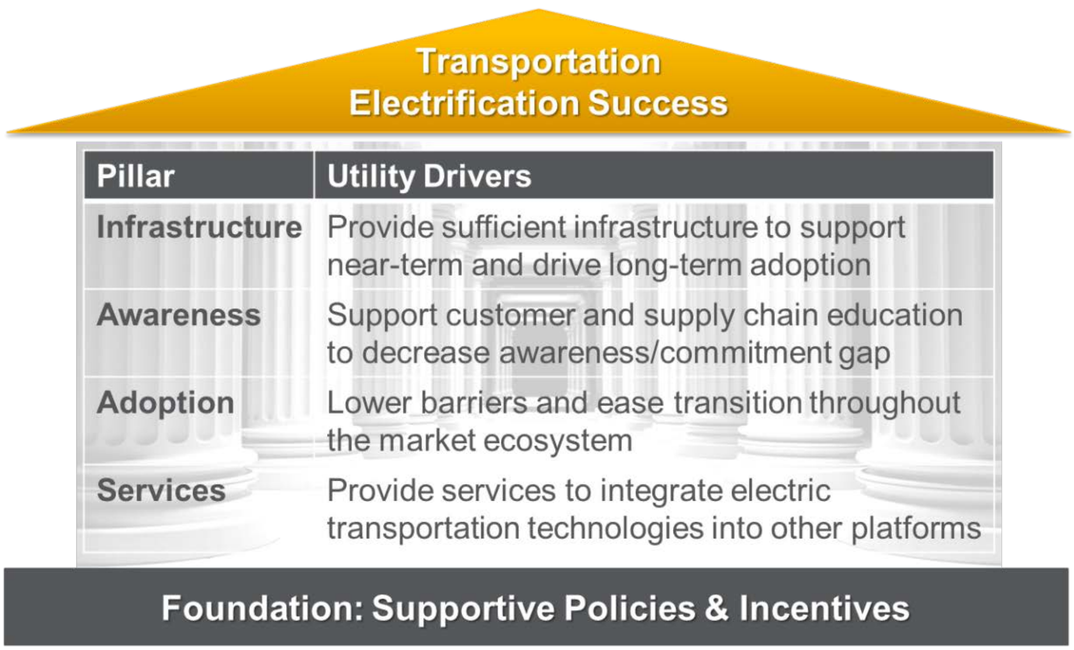
4.5 Task 5: V2H Commercial Value Proposition

The V2H commercial value proposition analysis approach leveraged findings from all work performed to analyze the drivers and barriers to V2H commercial availability and scale, recommend solutions to explore for addressing the barriers, and discuss likely California adoption.

4.5.1 Market Pillars for V2H Success

Realizing the commercial value of V2H requires conversion of VGI demonstrations and pilots into tangible and fruitful business models for energy services, DR, and grid ancillary services. Key market pillars for business models to target and address in the pursuit of V2H commercialization success include infrastructure, awareness, adoption, and services, as depicted in in Figure 32.

Figure 32. Key Pillars for Transportation Electrification Success[94]



Providing sufficient infrastructure to support near-term and drive long-term adoption, supporting customer and supply chain education to decrease the awareness gap, lowering barriers and easing the transition throughout the market ecosystem, providing services to integrate electric transportation technologies into other platforms will aid in successfully bringing electrification technologies into the market.

Drivers

The literature review of V2G technologies and demonstrations surfaced various promising drivers supporting V2H market commercialization. As previously discussed, demonstrations have incrementally leveraged lessons learned and added equipment in an evolutionary fashion to create four generations of V2G/V2H technology iterations. Though early challenges were encountered while seeking to accomplish V2G/V2H in a standardized way, now that the stakeholders have collaboratively

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[94] *Navigant Consulting, Inc.*, January 2017.

defined standards that the marketplace can develop to create new products and services, the challenges ahead lie in demonstration and implementation of the V2H technology.

In addition, although the upfront cost of the technology is high, the CBA indicates that bi-directional chargers are cost-competitive when compared to stationary storage, potentially allowing for greater market adoption. The project further identified through market stakeholder interviews that many recognize the V2G/V2H opportunity, and are exploring and developing solutions to current barriers. Finally, highly relevant data sources are available for most of the cost-benefit analysis requirements, indicating a V2H-related regulatory filing would be viable if the cost-benefit ratio improves over time.

Barriers

Key barriers to V2H commercialization identified by the project's findings and market stakeholder interview activities include unclear vehicle regulation, capital costs, limited value capture, standards implementation, and V2H arriving second to market behind stationary storage. While the barriers are currently impeding the commercialization progress of V2H technologies, several potential solutions are provided in Table 17 along with descriptions of the corresponding barriers.

Table 17. V2H Commercialization Barriers and Potential Solutions

Barrier	Description	Potential Solution
Vehicle Regulations Tied to Historic Market Approach	Current vehicle warranty policy dictated by regulations is based on time and/or miles.	OEMs receive support to update the warranty regulations.
Capital Costs	V2H is not cost-effective except from a program administrator perspective, without a participation incentive, because benefits are small relative to upfront capital costs.	Develop market or government regulatory mechanisms to minimize costs by increasing scale (*e.g.*, subsidies, resource aggregation, increased capacity requirements), which creates a better value proposition. Reduce upfront costs to maximize the long-term benefit of the service.
Limited Value Capture Opportunities for V2H on Reliable Grids	Low incremental value of V2H to reliable grids. This is because V2H's resiliency has an inverse relationship between ability to capture value versus resiliency/uptime of the existing grid.	Improve value capture by investigating technology that can provide both V2H and V2G services, rather than solely V2H, in problematic system locations (*e.g.*, issues with congestion, voltage, frequency) to maximize system flexibility/resiliency as well as reliability in a more cost-effective manner.
Solution Deployment Requires Unique Negotiation Each Time	Need to align market actors on methods to execute V2G/V2H standards.	Identify appropriate clearinghouse body to facilitate alignment on standard and protocol issues impacting commercialization. Broader commercialization requires a higher-level body like FERC/NERC, ISOs, or RTOs rather than more granular utility or state levels.
DER Competition Within Same Solution Space	Stationary storage, DR, Solar PV systems each offer a viable alternative and are already commercially available. Additionally, while vehicle-based solutions can have lower costs, they also have lower availability.	Market actors can potentially drive V2H competitiveness by focusing on scaling beyond individual systems to maximize value streams that benefit more than just the customer and communicating to customers the cost competitiveness if barriers are surmounted to increase adoption.

4.5.2 VGI Capacity Potential

The market for Vehicle-to-Grid Integration (VGI) growth that includes the V2G/V2H concepts has been examined for the US market. VGI reflects the amount of charging capacity installed at long-term parking locations and networks capable through either a bi-directional (V2G) or unidirectional (V1G) configuration. Though V2G is a subset of the broader VGI market, examining market trends are relevant to understanding the commercialization prospects for V2H in California.

Overall VGI potential is the rated capacity of infrastructure that could be feasibly integrated within grid services. This reflects all residential charging capacity and any long-term destination parking charging capacity (workplace, parking garage, multi-dwelling unit, fleet parking lot) that is networked and non-networked. Networked charging represents a portion of the VGI capacity potential and is more likely found in long-term destination parking and fleet parking locations than in residential locations. There are many uses for networked chargers outside of VGI, therefore only a portion of networked units would be smart charging (or VGI) capable. Smart charging (or VGI) appears in Figure 33 as VGI capacity by platform, and represents a small portion of networked charging.

Figure 33. VGI Capacity Potential, United States: 2017-2026[95]

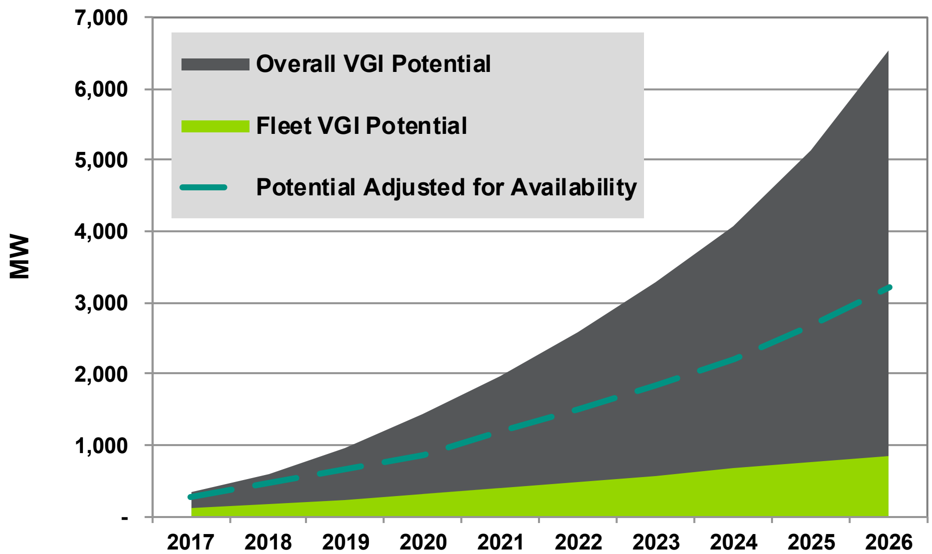
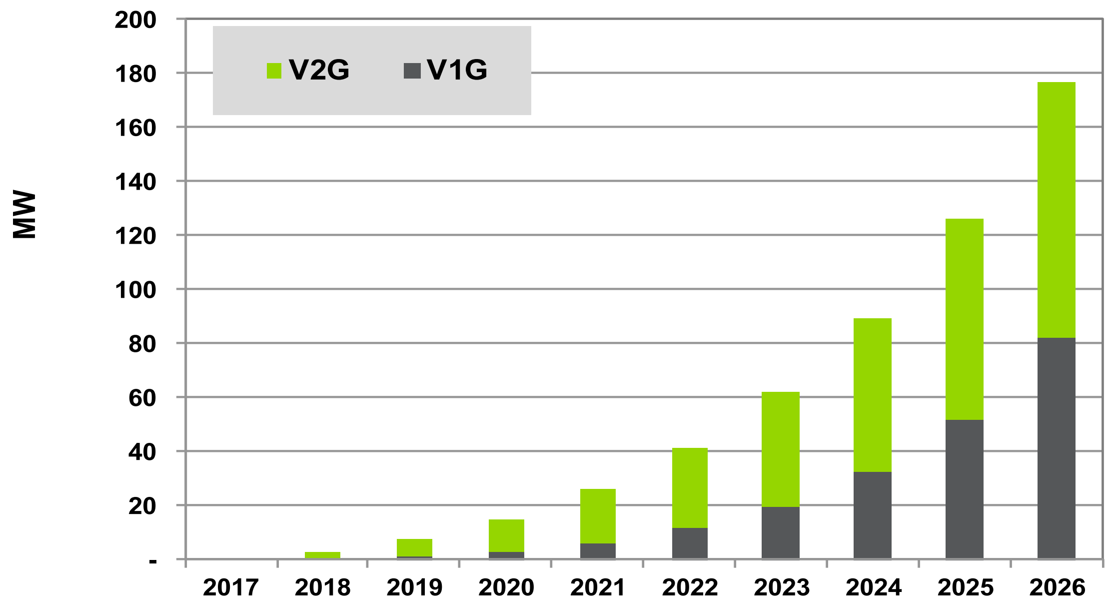


Figure 33 indicates that by 2019, the United States is expected to have nearly 1,000 MW of VGI potential with over 200 MW of fleet VGI potential that can be leveraged by wholesale markets, DR programs, or customers to realize the benefits of load shifting to serve their respective needs. California is likely to account for 50% of the EV population and thus has a high share of VGI potential. Availability constraints of V1G capacity (only available when connected and charging) and V2G capacity (only available when connected) limit actual potential of VGI, as well as the EV's capability to participate and driver willingness to participate.

Figure 34 indicates that V1G and V2G capacity is expected to account for nearly 8 MW in the United States by 2019.

[95] Navigant Research, "Vehicle Grid Integration," *Navigant Consulting Inc.,* 2015.

Figure 34. VGI Capacity by Platform, United States: 2017-2026[96]



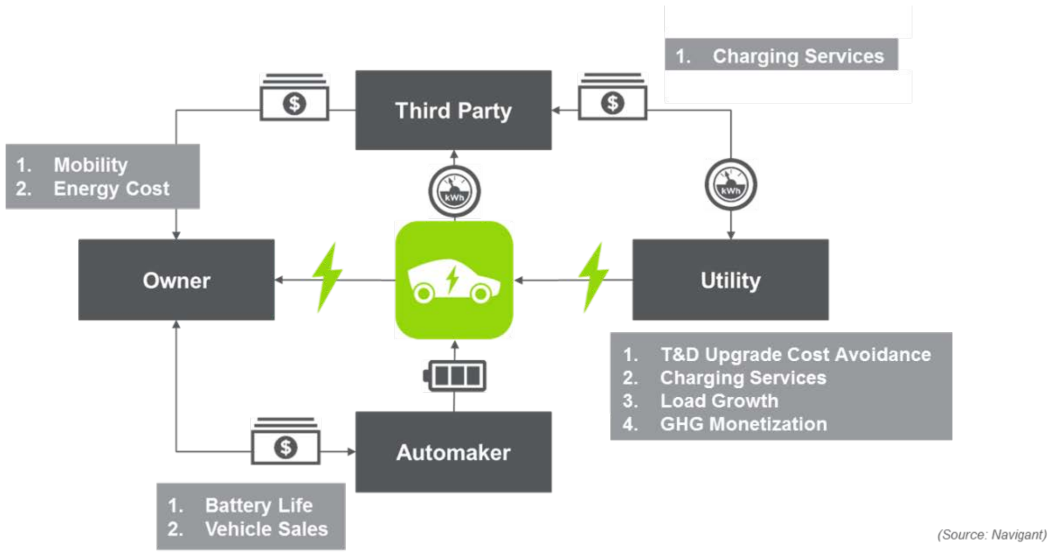
The VGI forecast in Figure 34 does not assume V2G capacity additions are made through V2H technologies. Consequently, developing a viable V2H business model that can capture relevant value streams would significantly impact the V2G capacity potential and deepen the impact of EVs on grid service markets.

4.5.3 Future V2H Value Streams

Recognizing that V2H represents an incremental growth opportunity for the VGI market, market actors have an opportunity to develop products and services that comply with the developed standards and monetize value streams to make V2H a commercially viable business model. Potential V2H value streams include DR and outage hard islanding. Additional value streams related to V2G charging and discharging services can flow between various market actors as depicted in Figure 35.

[96] Ibid.

Figure 35. V2G Value Streams[97]



Innovative business models must further define these V2G value streams by market segment and define tactical strategies to advance the technology toward market commercialization; as this occurs a combined V2H + V2G technology should be evaluated to understand if the benefits justify the increased technology costs. In California, surmounting V2H barriers will require carefully selecting strategic partnerships to explore and scale identified sources of value.

4.5.4 Conclusions

Partnerships among automakers, energy aggregators, charging networks, utilities, and mobility providers are needed, though they currently play complementary or competing roles. Decisions will pivot on the relevance and quality of data and insights into this unfamiliar and unfolding intersection of the local electricity and global transportation industries. Ultimately, illuminating these partnership opportunities and implementing aligned market entry strategies to aggregate resources at scale is critical to unlocking and capturing the V2H (and potential V2H + V2G) value streams.

[97] Derived from "Vehicle-to-Grid Value Streams," *Navigant Consulting, Inc.*, December 2015.

5 Value Proposition

The purpose of EPIC funding is to support investments in TD&D projects that benefit the electricity customers of PG&E, San Diego Gas & Electric, and Southern California Edison. EPIC 2.03.b has demonstrated that V2H technology is technically feasible and can potentially provide value to electric ratepayers and the load serving entities; however, the technology is precommercial (not available on the market) and only cost-effective for DR applications from a program administrator (PACT) perspective without a participation incentive, because benefits are small relative to upfront capital costs.

The project achieved its goal of bringing net new value to electric ratepayers, the load serving entities, and the broader marketplace by testing multiple residential load pattern use cases, exploring whether an EV can replace the functionality and benefits of an SS device, and evaluating incremental benefits from using both SS and an EV. Ultimately the project demonstrated that direct utility activity to commercialize V2H technology is not prudent at this time.

Consequently, the primary recommendation of this EPIC project is to better understand and develop the value propositions that V2H can provide. For example, the utility can plan and execute a field test of V2H technology with a market actor partner in the PG&E CAISO SSP program to ascertain actual interconnection, performance, and customer participation data. Participation would involve islanding a customer load in response to an award in the SSP and supporting the customer's critical loads with V2H EV discharge to understand whether costs and benefits can be improved compared to the assumptions used in this demonstration project. This effort would further inform the viability of commercializing V2H technology and understanding its potential benefits for PG&E customers and the utility from all cost test perspectives.

5.1 Primary Principles

The primary principles of EPIC are to invest in technologies and approaches that provide benefits to electric ratepayers by promoting greater reliability, lower costs, and increased safety. This EPIC project contributes to these primary principles in the following ways:

- **Greater Reliability**

  The project contributes to this principle by demonstrating technical feasibility at a proof-of-concept level that methods could be available to load serving entities for leveraging EVs to support DR activities during peak load and outage conditions. If the technology becomes commercially available, this capability could be useful to consider among other available approaches to support greater reliability across PG&E's system.

- **Lower Costs**

  The project contributes to this principle by demonstrating the technical feasibility of V2H and validating the costs and benefits of the V2H technology at a directional, site-specific level to vet the potential commercial prospects of the technology before dedicating ratepayer funds to support commercialization. The values produced by the project can be used by market actors and researchers to further investigate the commercial and financial prospects for improving the V2H technology value proposition and developing commercialization business models.

- **Increased Safety**

  The project contributes to this principle by exploring and documenting the interconnection requirements for V2H technology ahead of broader commercialization. Currently, bi-directional power flow-capable EVs are not commercially available in the United Sates. For V2H technology to become a mass market product, the automotive manufacturers will need to build EVs with these capabilities. Documenting these requirements can inform all market actors' understanding of safety considerations while pursing commercialization of the technology.

5.2 Secondary Principles

EPIC also has a set of complementary secondary principles. This EPIC project contributes to the following four:

- **Societal Benefits**

  Improved reliability support from V2H technology achieves a lower cost of service through a reduction in losses, lessening the overall cost of electric service to all customers, and is extended to society through shared economic interests in efficiency improvements.

- **GHG Emissions Reduction**

  V2H could maximize a customer's existing renewable generation (PV) by paring it with EV and potentially SS. These non-fossil fuel-based power generation technologies can facilitate reducing GHG emissions by offsetting any fossil fuel-based generation on PG&E's system.

- **Economic Development**

  The project supports PG&E's Grid of Things initiative by testing a smarter, cleaner, more reliable home with EVs. Advancing the commercial prospects for V2H technology through demonstration testing in PG&E's service territory, along with the subsequent benefits evaluation, provides tangible California-relevant market data that actors can use to advance the testing of V2H business models in California locations where the regulatory and market conditions are favorable to economic development of the concept. Delivery of a successful V2H business model would likely result in net new California jobs.

- **Efficient Use of Ratepayer Funds**

  The incremental investigation approach employed in EPIC 2.03b ensured efficient use of ratepayer funds by avoiding duplicative TD&D research. To ensure that EPIC 2.03b was incremental to all relevant previous demonstrations, the project conducted a market and regulatory assessment that summarized all relevant projects and lessons learned to date. A key result from this assessment was identifying the net new research questions that the project subsequently addressed. Consequently, the project builds on lessons learned from relevant previous projects that demonstrated the benefits of load shaving capabilities of delayed or reduced EV charging during DR events, including the BMW iChargeForward pilot in which PG&E was a project partner.

6 Accomplishments, Takeaways, and Recommendations

The key accomplishments, findings, takeaways, and recommendations of the EPIC 2.03.b project are of interest to PG&E and the wider utility industry.

6.1 Key Accomplishments

The following summaries cover the key accomplishments of the project over its duration:

- **Clarified Technical Distinctions that Separate V2G and V2H Functionalities**

  V2H and V2G are similar in that they both require bidirectional power flow (charging and discharging from an EV battery), however V2H and V2G are different sets of functionalities and the hardware and configurations to enable them are distinct. A V2H system operates only when a home is islanded from the grid a home during an outage to provide on-site resiliency or for residential DR participation (providing load drop by islanding the house). V2H is distinct from, and less complex than, a V2G configuration which requires a different equipment set up and integrates an EV into the electric distribution system to provide grid support services through bidirectional power flow from and to the grid. Until an EV charger is developed that contains both types of inverters, and the ability to appropriately switch between the two, a customer would have to choose which application they wish to pursue—V2H or V2G—and commensurately select the relevant inverter type for their EV charger.

- **Chronologized V2G Beginnings and Background and Characterized Generational Testing**

  Generally, development and assessment has focused on V2G technology; although, much of the technological advancements and lessons learned are pertinent for V2H as well. Most V2G/V2H testing and demonstrations occurring today grew out of initial test pilots by the University of Delaware (see Section 4.1.1). Overall, there has been an increase in the number of V2G/V2H demonstrations taking place globally in recent years, indicating interest in, and funding for, advancing these technologies, despite barriers currently in the market.

- **Characterized Technology and Market**

  Several barriers to commercialization exist for V2G and V2H technologies in the United States. OEMs are unwilling to mass produce vehicles capable of bi-directional energy flow until more testing has been completed and vehicle warranty issues are resolved. Currently, not all necessary technology is equipped to participate in grid services. From a utility standpoint, 100 kW of guaranteed minimum capacity for DR is typically required before a utility will allow new market entrants to participate in grid services. The implication for utilities and other potential V2G/V2H program administrators is the need for oversubscription to ensure adequate capacity during event calls or outages, since the mobile nature of EVs prevents 100% grid-connected availability. Based on technology barriers to V2G and V2H commercialization, the market needs continued testing, especially in residential and commercial settings. Key areas for investigation include hardware improvements that simplify and reduce costs of installation and operation, software integration with utility systems, customer awareness, customer willingness to accept participation incentives, and customer interest in other value streams such as load shifting.

- **Conducted Regulatory Examination**

  Overall, V2G and V2H standards are slowly becoming more aligned with market requirements, but key hardware, communication, and regulatory areas would benefit from further development or standardization to facilitate commercialization of V2G/V2H system components (see Figure 10). Many of the items that fall within this category are already actively being developed and are expected to be finalized within the next couple of years, such as the example standard underway (IEEE P825) for integration of DER with grid systems. There are other areas that are defined but do not yet have an active approach developed. A key example is the communication protocol defined via IEEE 2030.5 for controlling the charging and discharging of battery-based systems that does not yet have a best practice approach for market participants to implement with EVs. Sections 4.1.4 and 4.1.5 provide further detail on the relevant regulatory areas and considerations for V2H systems.

- **Conducted Customer Survey on Potential for V2H/V2G Adoption**

  The project conducted a concept test survey of PG&E's Customer Voice panel to better understand consumer interest in, and motivations for, adopting V2H/V2G technology. The survey also assessed the current market potential for such a product. The survey presented 400+ EV owners with the concept at a high level and successfully produced data that send clear directional signals about customer interest and willingness to pay for V2H capabilities.

- **Verified and Validated V2H System Technical Feasibility in a Lab Setting**

  Project testing was key to establishing the availability and viability of V2H technology. Scenario testing demonstrated the success of the EV to perform as a viable energy resource for the home, including integration with components involved in a V2H system configuration. The project's lab-based tests successfully demonstrated that the EV discharge was able to:

  - Perform cold load pick up and load following functions;
  - Serve as a voltage source allowing residential solar PV to generate and be utilized in islanded applications;
  - Parallel with solar PV and/or stationary storage to work in combination to provide electricity for household use;
  - Switch to charging mode and absorb solar PV generation that was in excess of household consumption; and,
  - Generally maintain voltage levels when islanded within the range of Rule 2 requirements.

  Validation testing demonstrated that the V2H system passed all test criteria for demand response and outage conditions, except in one test (number 70 as detailed in Section 4.2.3). Voltage in that test exceeded utility safety and standard parameters due to inclusion of large PV load. Additional testing should focus on expanded versions of that test as detailed in Section 4.2.

6.2 Key Findings & Takeaways

The project produced the following ***key findings*** and results:

- **V2H Technology is Technically Feasible but Not Commercially Available**

  The V2H system testing execution successfully demonstrated the feasibility of the EV (with or without SS pairing) to capture excess solar PV energy, act as current and/or voltage sources, act as frequency generators to enable solar PV to function in islanded situations, and properly transfer and handle cold loads in loss of grid situations—all while generally maintaining safety and operating within utility requirements. One test failed when utility voltage requirements were exceeded; although such technology may not be subject to Rule 2, it should be developed and tested to ensure it adheres to appropriate voltage sensitivities for islanded residential use. Setting up the lab test as well as surveying the market determined that V2H hardware and software is not available on the market, components need to be commercialized with a focus on simplifying and minimizing installation and operation costs.

- **Expected V2H System Costs Outweigh the Quantifiable Benefits**

  The cost-benefit analysis framework developed for this project assessed V2H system cost-effectiveness as a participating resource in the PG&E CAISO SSP program under five different tests to determine the value of V2H to customers, utilities, and society. The cost-benefit analysis quantitatively demonstrated that the value of V2H varies significantly depending on the stakeholder viewpoint. The primary driver of the net benefits was the allocation of equipment capital costs among stakeholders. The tested configurations are cost-effective under the program administrator tests (RIM and PACT), but not cost-effective from the customer (PCT) and society (SCT and TRC) perspectives. These three tests that consider the customer perspective all produce a cost-benefit ratio of less than 1 primarily because of the upfront customer capital cost. A separate scenario (EV with Incentive) considered the cost-effectiveness if the customer received a $2000 incentive to install the V2H system (the *minimum* incentive level that would result in customer adoption according to the project's Customer Survey results), the benefit-cost ratio results were less than 1 for all five tests.

- **Customer Willingness to Pay Lower than Estimated V2H System Cost**

  The cost-effective result under the RIM and PACT tests rests on the assumption that a small incentive payment would be sufficient to garner customer participation in a demand response program after the customer has already adopted the V2H technology due to the outage support it can provide. This assumption was validated by the customer survey which found that the most appealing attributes of the V2H technology concept were emergency preparedness and retaining power during an outage (see Appendix G . Project results indicate there could be up to $1,389 in net benefits available to incent participation (see Table 14); however, a $1,389 participation incentive does not close the gap between the estimated price of a V2H system to the customer ($4,500[98]), and the optimal price (willingness to pay)

[98] The cost estimate used in the customer survey for a V2H system includes a hypothesized bi-directional charger and installation cost of $2,400 (Table 10) as well as estimated critical panel costs (transfer switch, panel equipment, switch box) and installation of $2,100. Critical panel costs are hypothesized based on anecdotal market-based quotes obtained by PG&E for the purposes of the customer survey. There is a high degree of uncertainty in the estimate due to the lack of a commercially available bi-directional charger, and therefore, a lack of procurement and installation experience by the supply chain for a full V2H system. The figures used are intended to provide directional results until the technology achieves commercialization in the California market, and better data become available for further analysis.

determined in the customer survey ($800). Further, the net benefits fall below an estimated *minimum* incentive level of $2000 which would interest only the least price sensitive respondents to the customer survey. After the technology becomes commercially available, determining whether utilities and other potential program administrators should develop programs encouraging adoption of V2H systems may require further investigation into customer awareness, willingness to accept participation incentives, and interest in other value streams, such as load shifting.

- **High Customer Interest in Emergency Preparedness but Costs Outweigh Perceived Benefits**

  Interest in V2H is very high among EV Owners, as more than half said they would be very interested in the technology; however, interest significantly declines to less than 10% following presentation of the estimated price (about $4,500[99]). As mentioned, the customer survey indicated that the optimal price for a full V2H system to be around $800. Notably, at a price above $1,000 customer interest drops dramatically as consumers do not feel that the frequency of power outages justifies the expenditure.

  Respondents viewed the technology primarily as an emergency preparedness (resiliency) tool and/or a way to retain power during an outage—and to a lesser degree as a way for them to save money on their bills (only available with V2G functionality and NEM) or earn incentives (i.e. demand response participation via either V2H or V2G). While most customers have experienced multiple power outages, they tend to be infrequent and of short duration. As a result, relatively few (about one in ten) are very concerned about outages. There is a potential marketing opportunity for EV manufacturers to appeal to a small group of potential EV consumers. About 12% said they would be much more likely to consider purchasing an EV if V2H technology were available.

- **Multiple Types of Barriers to V2H Commercialization Exist**

  The cost-benefit analysis and the market and regulatory assessment identified barriers and drivers to V2H commercialization. Key barriers to V2H commercialization identified by the project's research and market stakeholder interview activities include cost, unclear path to resolve battery warranty issues (currently V2H or V2G export voids warranty), value capture limited with V2H functionality, standards implementation, and V2H arriving second to market behind stationary storage. While the barriers are currently impeding the commercialization progress of V2H technologies, potential solutions identified by the project (see Table 17) include: partnerships between stakeholders; increasing value capture; and scaling beyond individual systems to reach market-ready products.

- **Opportunities are Available for V2H Commercialization**

  V2H and V2G can provide several value streams including DR, outage hard islanding, and consumer-driven load shifting that can flow between various market actors. Market actors will need to define new business models and evaluate them against the cost of V2H, V2G, or a combo technology to determine when and how to advance the technology to market commercialization. Partnerships among automakers, energy aggregators, charging networks, utilities, and mobility providers will likely be needed.

[99] Estimated full cost of V2H system (technology and installation, but not the cost of an export capable EV) is higher than the incremental cost value used for the cost benefit analysis as explained in Section 3.4 . The survey tested customer reaction to estimated full system cost even for customers who already have level 2 charging installed, because V2H implementation will require all new hardware.

Based on the key findings and results, PG&E identified the following ***key takeaways*** and lessons learned from this project:

- **Adequate Demand Response Mechanisms Exist in California to Leverage V2H Systems**

  The project demonstrated that the requisite demand response mechanisms and processes with sufficient flexibility to realize benefits from resources like V2H systems, once they are available and affordable, exist in California. In particular, the flexibility provided by PG&E's CAISO SSP program that allows market actors to offer and aggregate commercially viable resources relative to electric CAISO market needs, provides a viable venue for fostering the V2H market.

- **Key Question: Home Energy Storage or Electric Vehicle?**

  Answer: V2H system may be able to substitute for stationary storage, depending on customer mobility and home electricity needs.

  The project found that an EV-only V2H system can replace the hard islanding and DR functionality of a stationary storage device, and provide greater net benefits *when the EV is connected to the system and at suitable level of charge*. However, the overall net benefits to an individual customer will depend on that customers' mobility and household electricity needs at the exact moment of an outage or DR event. For example, if an outage occurs while the EV is away from home, a single customer may not care about the loss of their V2H resiliency benefit because both they and the EV were away from home during the event. Conversely, a customer who is away from home, but has other household members at home during the event, may not value the outage support of the EV as highly as SS because the resiliency benefit of V2H functionality is not available to the non-driving household members when the EV is not at home. PG&E expects that real-world field results will vary based on a host of conditions including V2H system setup, selected hardware, customer objectives, etc.

- **Key Question: Home Energy Storage and Electric Vehicle? resiliency**

  Answer: V2H system with solar PV and stationary storage can provide significant resiliency benefits in the case of sustained outages.

  The project found that a V2H system with solar PV and stationary storage provides significant, compounded resiliency benefits in the case of sustained outages. The analysis showed that combining both solar PV and stationary storage systems provided enough storage for the solar PV system to be effective in recharging the stationary storage during the day for use at low/no solar availability, such as at night. With the combined system, the additional storage capacity enables the V2H system to serve household load for multiple days—even during the summer—and approaches multi-week coverage during high solar/low demand times, like the shoulder seasons. However, this resiliency benefit will need to be balanced with mobility needs. Notably, these incremental benefits come at a significant incremental cost to the V2H system owner due to the upfront costs of the system components related to both the EV and SS. Also, it is not clear whether the additional resiliency hours for the site owner translate into value for the utility or society. PG&E expects that real-world field results will vary based on a host of variables including V2H system setup, selected hardware, customer objectives, etc.

- **Once V2H/V2G technology is commercially available, early adoption is likely to be motivated by V2H resiliency and reliability benefits.**

  In the customer survey, when customers considered the functionality of both V2H and combined V2H/V2G systems they were significantly more interested in the V2H functionalities of being prepared in case of an emergency and retaining power during an outage than in functionalities that involved interacting with the grid. This finding indicates that that business models built to offer V2H functionality are likely to gain early traction over V2G-focused business models. The finding further indicates that V2H benefits will accrue primarily to individuals, at least in the initial adoption stages. However, this early adoption market may be small as only 12% of customers indicated they were very concerned about outages.

- **After a V2H system is adopted by a customer for personal resiliency and reliability benefits, utilizing an EV and V2H system for a demand response event is cost-effective from a program administrator cost test perspective.**

  The testing of new, unproven technology is an important process for the cost-conscious utility. The cost-benefit analysis performed for this project indicates that using an EV to respond to a demand response event is a cost-effective program when considering the demand response capacity benefits to a program administrator; however, it is only cost-effective under this test if the customer bears the equipment capital costs of the EV-only V2H system. In PG&E's survey, customers indicated that the reliability and resiliency benefits were their primary interests in the technology. Once a customer has adopted a V2H system to gain these personal benefits, enrollment in a utility program can bring additional value. PG&E expects that the value of reliability and resiliency will vary for individual customers and that real-world cost results will vary based on a host of variables including V2H system setup, selected hardware, customer objectives, etc.

- **Several key secondary drivers may lead to cost-effective scenarios in the future, including declining overall technology costs and stacking additional storage value streams.**

  V2H was not found to be cost-effective from the participant's perspective, due to the cost of the enabling technology. In the future, if the costs of the enabling technology decline below the assumptions used in this analysis or if other value streams become available and can be stacked then a V2H system could become cost-effective from the participant's perspective. Future analysis should consider the O&M and battery lifetime costs of enabling these value streams.

- **Both key drivers and barriers exist to V2H commercialization.**

  Through the cost-benefit analysis and the market and regulatory assessment, barriers and drivers to V2H commercialization were identified (see Table 2). Solutions to the presented barriers highlighted partnerships between stakeholders, increasing value capture, and scaling beyond individual systems to reach market-ready products.

6.3 Key Recommendations

The following summary of key recommendations is of interest to PG&E and the wider utility industry:

- ***Research* – Conduct additional investigations to address barriers in nascent V2H market ahead of policy interventions.**

  The lack of commercially available technologies for a full V2H system in California today, and the low cost-benefit ratio results from the customer and societal perspectives demonstrate that V2H is still a nascent market in the state. If market actors can overcome the barriers identified through this project, and develop business models proven to provide benefits to the customer, utility, and society, PG&E and other utilities can investigate the following deployments:

  - Enroll residential customers that have V2H technology in applicable DR programs.
  - Provide hardware and services to residential customers to allow for DR participation or independent islanding.

- ***Policy* – Early adopters of V2H are likely to be motived by individual benefits, spurring a need for policy discussions on V2H to recognize that publicly funded incentives are not likely to accrue benefits to other ratepayers or society.**

  The customer survey indicates that interest in V2H technology is primarily motivated by the desire for resiliency and reliability benefits. If the V2H technology is primarily used for those purposes rather than for participation in DR programs, the benefits will mainly accrue to the individual customer rather than ratepayers or society as a whole. Therefore, future policy and program design must consider what, if any, level of subsidization for customer installation V2H technology is appropriate.

- ***Technology* – Investigate optimal system configurations from all cost test perspectives for all system configurations (EV, SS, EV+SS) through a field test of V2G/V2H technology with a market actor partner in PG&E's CAISO SSP program.**

  Additional investigation into cost-effectiveness while ascertaining actual interconnection, performance, and customer participation data would aid in understanding: the incremental value of connecting both the main and critical panels; V2H product development to enhance DR event capacity offerings; and benefits incremental to DR/outage.

  For example, currently V2H requires off-board hardware to handle transfer switch functions for isolating in islanding mode. In the future, the ability to use AC ports as well, and on-board hardware that includes more functionality—such as handling transfer switch functions—could achieve further cost reductions. Such research could explore a potential policy or market intervention to leverage the vehicle's DC connection for power export capabilities. This intervention would require that a stakeholder incur the cost of external equipment to overcome the designed limited functionality[100] of current vehicle hardware used for power export. Notably, the stakeholder that incurs this equipment cost would address the capital cost barrier by allowing the equipment specifications and standardization to evolve on a track

[100] Automakers must tradeoff technology capability, cost, and market readiness when selecting on-board equipment relevant for power export as identified in stakeholder interviews described in 4.1.1 .

independent of the vehicle's lifecycle, thereby providing flexibility that could support V2H/V2G commercialization.

- ***Benefits* – Investigate value of resiliency to the customer as well as customer load during periods of long sustained outages.**

  The completed testing for EPIC 2.03b incorporated short-term outages. To better understand the value of resiliency to the customer, PG&E recommends further testing and investigation take place to analyze longer-term outages. Questions to address include: what is a customer's willingness to pay for resiliency, and what conservation behaviors can we expect during long-term outages?

- ***Benefits* – Investigate additional system benefits that would be produced if bi-directional chargers capable of both V2H and V2G were available and whether network effects could increase these benefits.**

  If bi-directional chargers capable of both V2H and V2G are available and garner customer interest, the potential to utilize V2G is possible; however, further testing and investigation is required. Market actors can drive V2G competitiveness by focusing on scaling these systems to maximize value streams and communicating the value proposition to customers, if barriers are surmounted, to increase adoption.

- ***Costs* – Investigate policy or market intervention opportunities to minimize upfront capital costs to make V2H cost-effective from a customer perspective.**

  The nascent V2H market would benefit from developing market or government regulatory mechanisms to minimize costs by increasing scale to help create a better value proposition for V2H technology. Reducing upfront capital costs could maximize the cost effectiveness of V2H. The customer survey indicates that an optimal price of around $800 for total V2H system set up, though current estimates exceed that by 4-5 times.

- ***Standards* – Investigate opportunities to align market actors and governing standards bodies on methods to execute V2G/V2H standards.**

  Identifying an appropriate clearinghouse body to facilitate aligning standard and protocol issues impacting commercialization would streamline standards implementation. Broader commercialization requires a higher-level body (*e.g.*, FERC/NERC, ISOs, or RTOs) rather than more granular utility or state level entities.

7 Technology Transfer Plan

7.1 PG&E Technology Transfer Plans

A primary benefit of the EPIC program is the technology and knowledge-sharing that occurs both internally within PG&E and across the other IOUs, CEC, and the industry. To facilitate this knowledge-sharing, PG&E will share the results of this project in industry workshops and through public reports published on the PG&E website.

PG&E has already started sharing the knowledge internally via meetings and presentations and will continue to do so targeting groups that deal with V2H related issues such as Service Planning, Grid Planning, Clean Energy Programs, and Grid Integration and Innovation. External outreach will be targeted at automakers and manufacturers of residential Level 2 chargers. Additional stakeholder outreach will include policymakers and companies in the distributed energy resources sector that could interact with a V2H system, such as residential stationary storage and residential PV. PG&E has already shared learnings with an interested automaker and will continue to facilitate meetings to walk interested stakeholders through the results. In addition, PG&E plans to present the project to group audiences at several knowledge sharing venues (see Table 18)

Table 18. Planned Knowledge Sharing Venues

Name	Description	Timing/Location
Storage Week	National conference focused on development and finance of energy storage projects of all sizes.	February 2018 San Francisco, CA
EPRI Electric Vehicle Infrastructure Working Council	Convening group of US utilities and international companies engaged in EV infrastructure issues.	Q2 2018
2018 CEC EPIC Symposium	Statewide symposium discussing project results and other EPIC program highlights.	Q4 2018

7.2 Adaptability to Other Utilities and Industry

PG&E currently has the most EVs in its service territory of any utility in the United States and PG&E is often a harbinger of interest in new EV technology. As EV adoption continues and increases in other areas across the country, those utilities will likely also encounter interest in V2H technology. Understanding the technical feasibility and potential value that V2H systems offer the utility and its customers during peak load and outage conditions provides key learnings that utilities can factor into their planning. The following findings of this project are relevant and adaptable to other utilities and the industry:

- **V2H system configurations verified and validated in a lab setting.**

  Project testing was key to establishing the viability of V2H technology. Scenario testing demonstrated the success of the EV to perform as a viable energy resource for the home, including integration with components involved in a V2H system configuration. The various lab-based tests involving load following, the handoffs between components under load (stationary storage battery, EV, and solar PV), and in response to islanding events (demand response and outage), were successful. Validation testing demonstrated that the V2H system passed all test criteria for demand response and outage conditions, with one area identified for future investigation. Voltage in Test 70 exceeded utility safety and standard parameters due to inclusion of large PV load. Additional testing is suggested to focus on expanded versions of Test 70 as detailed in Section 4.2.

- **After a V2H system is adopted by a customer for personal resiliency and reliability benefits, utilizing an EV and V2H system for a demand response event is cost-effective from a program administrator cost test perspective.**

  The testing of new, unproven technology is an important process for the cost-conscious utility. The cost-benefit analysis performed for this project indicates that using an EV to respond to a demand response event is a cost-effective program when considering the demand response capacity benefits to a program administrator; however, it is only cost-effective under this test if the customer bears the equipment capital costs of the EV-only V2H system. In PG&E's survey, customers indicated that the reliability and resiliency benefits were their primary interests in the technology. Once a customer has adopted a V2H system to gain these personal benefits, enrollment in a utility program can bring additional value. PG&E expects that the value of reliability and resiliency will vary for individual customers and that real-world cost results will vary based on a host of variables including V2H system setup, selected hardware, customer objectives, etc.

- **The V2H system with solar PV and stationary storage provides significant resiliency benefits in the case of sustained outages.**

  The project found that a V2H system with solar PV and stationary storage provides significant, compounded resiliency benefits in the case of sustained outages. The analysis showed that combining both solar PV and stationary storage systems provided enough storage for the solar PV system to be effective in recharging the stationary storage during the day for use at low/no solar availability like at night. With the combined system, the additional storage capacity enables the V2H system to serve household lead for multiple days—even during the summer—and approaches multi-week coverage during high solar/low demand times, like the shoulder seasons. However, this resiliency benefit will need to be balanced with mobility needs. Notably, these incremental benefits come at a significant incremental cost to the V2H system owner due to the upfront costs of the system components related to both the EV and SS. Also, it is not clear whether the additional resiliency hours for the site owner translate into value for the utility or society. PG&E expects that real-world field results will vary based on a host of variables including V2H system setup, selected hardware, customer objectives, etc.

8 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

9 Metrics

PG&E identified the following metrics for this project and are included in PG&E's EPIC Annual Report as potential metrics to measure project benefits at full scale.[101] Given the proof-of-concept nature of this EPIC project, these metrics are forward looking.

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement (as applicable to a specific project or investment area)	**Section**
3. Economic Benefits	
a. Maintain/reduce operations and maintenance costs	The cost-benefit analysis (described in Sections 4.3 and 4.4) highlighted cost-effectiveness from a program administrator perspective—without a participation incentive—while the commercialization analysis (Section 4.5) proposed solutions to reduce the cost of V2H system implementation from other stakeholder perspectives
7. Identification of Barriers or Issues Resolved that Prevented Widespread Deployment of Technology or Strategy	
d. Deployment and integration of cost-effective distributed resources and generation, including renewable resources (PU Code § 8360)	Project activities—including testing a proof-of-concept V2H system, a V2G/V2H market assessment, and cost-benefit analysis—collectively identified and recommended strategies for lowering the barriers to adoption for this smart grid technology and potential customer service. Investigation included a cost-benefit analysis that analyzed potential scenarios comparing a residential storage battery and EV (Section 4.4). Investigation further provided insights into V2H system technical, commercial, and regulatory requirements that inform how far current technologies can serve customer and utility business needs (Sections 4.1.2 , 4.1.4 , and 4.5).

[101] Pacific Gas and Electric Company Electric Program Investment Charge 2016 Annual Report. Feb 28, 2017, Appendix A, p. 48, https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/2016-EPIC-Annual-Report.pdf.

10 Conclusion

As a result of the EPIC 2.03b initiative, PG&E has accomplished its objectives and gained additional insights into the technical feasibility and potential value of V2H technology during peak load and outage conditions. Although the project successfully demonstrated the technical feasibility of a V2H system, and determined that utilizing it as a demand response resource could be cost effective from a program administrator perspective, V2H is a nascent market and the technology is not ready for PG&E to proceed with commercialization activities. This conclusion stems from the lack of commercially available technologies for a full V2H system in California today, and the low cost-benefit ratio results from the customer and societal perspectives. These results indicate that the nascent V2H market requires further investigation to better understand optimal approaches to address cost and other market barriers ahead of policy intervention.

In the interest of investigating optimal approaches, the primary recommendation of this EPIC project is to plan and execute a field test of V2H technology with a market actor partner in PG&E's CAISO SSP program. This effort would seek to test optional system configurations while ascertaining actual interconnection, performance, and customer participation data. The investigation would further test the value of resiliency to the customer over short and long-term outage durations. In undertaking these areas of investigation, this effort would further inform the viability of commercializing V2G/V2H technology and understanding its potential benefits for electric ratepayers and load serving entities from all cost test perspectives.

The project also proposes investigations of potential solutions to address V2H market barriers. The customer survey demonstrates that the upfront capital cost will be a significant barrier. The project recommends investigating methods to lower that cost, such as whether alternate charger technology that leverages the vehicle's DC connection for power export, could be less costly. Finally, the project recommended identifying an appropriate clearinghouse to facilitate market actor alignment on consistent methods for executing existing and emerging V2H-related standards and protocols.

Notably, the project demonstrated that the requisite demand response mechanisms and processes with sufficient flexibility to realize benefits from resources like V2H systems, once they are available and affordable, exist in California. In particular, the flexibility provided by the PG&E CAISO SSP program that allows market actors to offer and aggregate commercially viable resources relative to electric system needs, provides a viable venue for fostering the V2H market. If market actors can overcome the barriers identified through this project and develop business models that improve the cost-effectiveness of the technology, and the affordability of residential electricity, PG&E's programs will support deployments.

Ahead of such deployments, partnerships among automakers, energy aggregators, charging networks, utilities, and mobility providers could help to advance the market; though this is expected to be challenging initially due to lack of business model clarity and uncertainty around which stakeholders will play complementary or competing roles. Decisions will pivot on the relevance of V2H capabilities to global transportation industries. Ultimately, finding these partnership opportunities, implementing aligned market entry strategies, and building sustainable business models will be critical to unlocking and capturing the V2H value streams.

PG&E’s work to validate the feasibility and potential value of V2H technology has significance for the entire industry—in particular for utilities that are experiencing customer interest in using the same technology. These findings will be shared with other utilities at industry conferences, events, and technical forums.

11 APPENDICES

Appendix A - SAE Vehicle-to-Grid/Home Standards

SAE Standard	Title	Objective	Link
J1772	Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler	Defines a common EV/PHEV and supply equipment vehicle conductive charging method.	http://standards.sae.org/j1772_201602/
J2293/1	Energy Transfer System for Electric Vehicles - Part 1: Functional Requirements and System Architectures	Establishes requirements for Electric Vehicles (EV) and the off- board Electric Vehicle Supply Equipment (EVSE) used to transfer electrical energy to an EV from an Electric Utility Power System (Utility).	http://standards.sae.org/j2293/1_200807/
J2293/2	Energy Transfer System for Electric Vehicles - Part 2: Communication Requirements and Network Architecture	Establishes requirements for Electric Vehicles (EV) and the offboard Electric Vehicle Supply Equipment (EVSE) used to transfer electrical energy to an EV from an electric Utility Power System (Utility)	http://standards.sae.org/j2293/2_200807/
J2344	Guidelines for Electric Vehicle Safety	Identifies and defines the preferred technical guidelines relating to safety for Electric Vehicles (EVs) during normal operation and charging.	http://standards.sae.org/j2344_201003/
J2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing	Describes a body of tests which may be used as needed for abuse testing of electric or hybrid electric vehicle batteries to determine the response of such batteries to conditions or events which are beyond their normal operating range.	http://standards.sae.org/j2464_200911/
J2836/1	Use Cases for Communication Between Plug-in Vehicles and the Utility Grid	Establishes use cases for communication between plug-in electric vehicles and the electric power grid, for energy transfer and other applications.	http://standards.sae.org/j2836/1_201004/
J2836/2	Use Cases for Communication between Plug-in Vehicles and the Supply Equipment (EVSE)	Establishes use cases for communication between plug-in electric vehicles and the electric vehicle supply equipment, for energy transfer and other applications.	http://standards.sae.org/j2836/2_201109/
J2836/3 (WIP)	Use Cases for Communication between Plug-in Vehicles and the Utility Grid for Reverse Power Flow	Establishes use cases for communication between plug-in electric vehicles and the electric power grid, for reverse power flow.	http://standards.sae.org/wip/j2836/3/
J2836/4 (WIP)	Use Cases for Diagnostic Communication for Plug-in Vehicles	Establishes diagnostic use cases between plug-in electric vehicles and the EV Supply Equipment (EVSE).	http://standards.sae.org/wip/j2836/4/
J2836/5 (WIP)	Use Cases for Communication between Plug-in Vehicles and their customers	Establishes use cases between Plug-In Vehicles (PEV) and their customer.	http://standards.sae.org/wip/j2836/5/
J2836/6 (WIP)	Use Cases for Wireless Charging Communication between Plug-in Electric Vehicles and the Utility Grid	Wireless charging use cases	http://standards.sae.org/wip/j2836/6/

SAE Standard	Title	Objective	Link
J2847/1	Communication between Plug-in Vehicles and the Utility Grid	Establishes requirements and specifications for communication between plug-in electric vehicles and the electric power grid, for energy transfer and other applications.	http://standards.sae.org/j2847/1_201311/
J2847/2	Communication between Plug-in Vehicles and offboard DC Chargers	Establishes requirements and specifications for communication between Plug-in Electric Vehicles (PEV) and the DC 0ff-board charger	http://standards.sae.org/j2847/2_201504/
J2847/3	Communication between Plug-in Vehicles and offboard DC Chargers	Establishes the communication structure between plug-in electric vehicles and the electric power grid, for reverse power flow.	http://standards.sae.org/j2847/3_201312/
J2847/4 (WIP)	Diagnostic Communication for Plug-in Vehicles	Establishes the communication requirements for diagnostics between plug-in electric vehicles and the EV Supply Equipment (EVSE) for charge or discharge sessions.	http://standards.sae.org/wip/j2847/4/
J2847/5 (WIP)	Diagnostic Communication for Plug-in Vehicles	Establishes the communication requirements between plug-in electric vehicles and their customers for charge or discharge sessions.	http://standards.sae.org/wip/j2847/5/
J2847/6 (WIP)	Wireless Charging Communication between Plug-in Electric Vehicles and the Utility Grid	Wireless charging messages, signals, etc.	http://standards.sae.org/wip/j2847/6/
J2894/1	Power Quality Requirements for Plug-In Vehicle Chargers - Part 1: Requirements	Provides guidelines and standards for the quality of the charging voltage and current at the vehicle itself.	http://standards.sae.org/j2894/1_201112/
J2894/2	Power Quality Requirements for Plug-In Vehicle Chargers - Part 2: Test Methods	Address automatic charger restarts after a sustained power outage, as well as the ability to ride through momentary outage	http://standards.sae.org/j2894/2_201503/
J2929	Electric and Hybrid Vehicle Propulsion Battery System Safety Standard - Lithium-based Rechargeable Cells	Defines a minimum set of acceptable safety criteria for a lithium-based rechargeable battery system	http://standards.sae.org/j2929_201302/
J2931/1	Power Line Carrier Communications for Plug-in Electric Vehicles	Establishes the digital communication requirements for the Electric Vehicle Supply Equipment (EVSE) as it interfaces with a Home Area Network (HAN),	http://standards.sae.org/wip/j2931/1/
J2931/2 (WIP)	In band Signaling Communication for Plug-in Electric Vehicles	Establishes the requirements for physical layer communications using In band Signaling between Plug-In Vehicles (PEV) and the EVSE.	None
J2931/3 (WIP)	PLC Communication for Plug-in Electric Vehicles	Establishes the requirements for physical layer communications using Power Line Carrier (PLC) between Plug-In Vehicles (PEV) and the EVSE.	None

SAE Standard	Title	Objective	Link
J2931/4 (WIP)	Broadband PLC Communication for Plug-in Electric Vehicles	Establishes the requirements for physical and data-link layer communications using broad band Power Line Carrier (PLC) between Plug-In Vehicles (PEV) and an EVSE, DC offboard-charger or direct to the utility smart meter or Home Area Network (HAN).	http://standards.sae.org/j2931/4_201410/
J2931/5 (WIP)	Telematics Smart Grid Communications between Customers, Plug-In Electric Vehicles (PEV), Energy Service Providers (ESP) and Home Area Networks (HAN)	Communication protocol including V2V, V2I telematics	http://standards.sae.org/wip/j2931/5/
J2931/6 (WIP)	Digital Communication for Wireless Charging Plug-in Electric Vehicles	Wireless charging communication protocol	http://standards.sae.org/wip/j2931/6/
J2931/7 (WIP)	Security for Plug-in Electric Vehicle Communications	Electric Vehicle communication security protocols	http://standards.sae.org/wip/j2931/7/
J2953 (WIP)	Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE)	Establishes the interoperability requirements and specifications for the communication systems between Plug-In Vehicles (PEV) and Electric Vehicle Supply Equipment (EVSE) for multiple suppliers.	http://standards.sae.org/j2953/1_201310/

Appendix B - Generational Graphics

Table 19. Generational V2G Technology Timeline

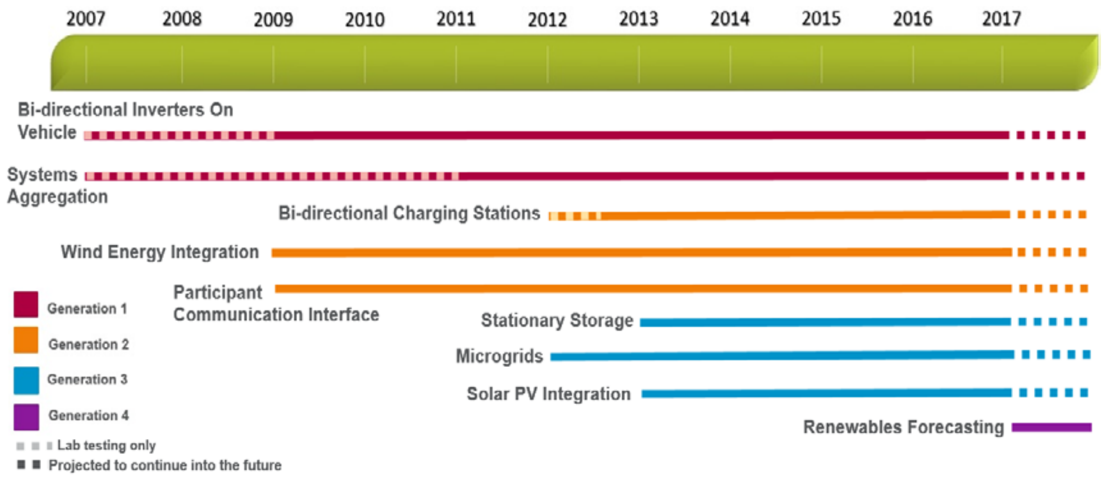
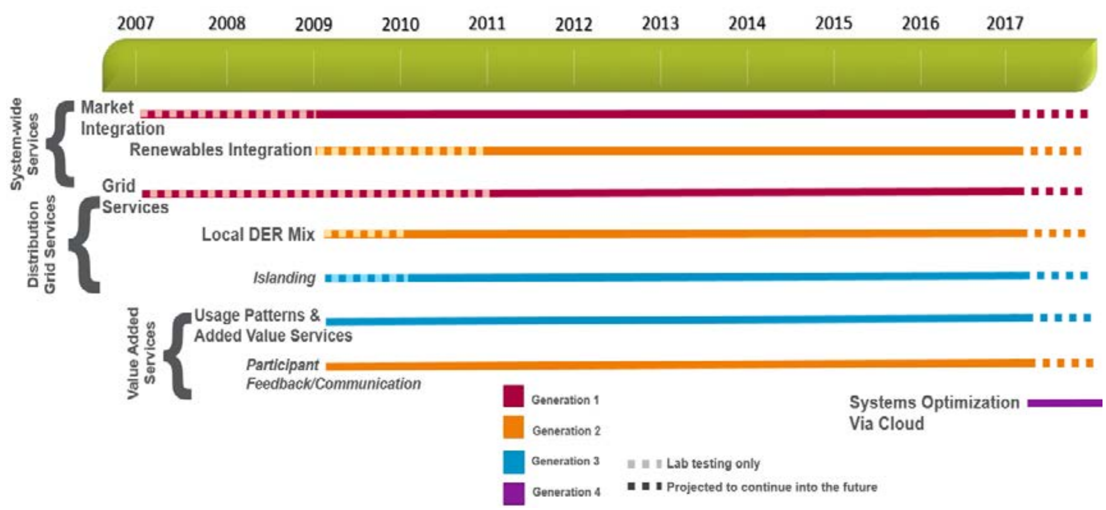


Table 20. Generational V2G Services Timeline



Appendix C - V2H Testing Scenarios

Table 21. V2H Testing Scenarios

Scenario	Description	Test Number	Primary Equipment			Success Criteria Tested				
			SS	PV	EV	Islanding (Outage / Demand Response)	Paralleled Resources	Cold Load Pickup	Rule 2 Voltage Range	Load Following
Verification	Residential SS baseline performance without solar PV	14, 17-26, 33-35, 39-58	X			Pass	Pass	Pass	Pass	Pass
	Residential stationary storage (SS) baseline performance with solar PV	15-16, 27-32	X	X		Pass	Pass	N/A	Pass	Pass
Validation	Electric Vehicle (EV) supporting residential load in an Island mode, varying conditions	1, 69			X	Pass	N/A	N/A	Pass	Pass
	EV supporting residential load in an Island mode. EV acting in Grid Support Mode, varying cold load pickup in 1 kW increments.	2-6			X	Pass	N/A	Pass	Pass	N/A
	EV supporting residential load in an Island mode with PV, varying conditions	7-13, 70		X	X	Pass	Pass	Pass	Pass (7-13) Fail (70)	Pass
	EV supporting residential load in an Island mode with SS, varying conditions	66	X		X	Pass	Pass	Pass	Pass	Pass
	EV supporting residential load in an Island mode with PV and SS, varying conditions	36-37, 67-68	X	X	X	Pass	Pass	Pass	Pass	Pass

Appendix D - Snapshot Efficiency Tool Inputs: Fresno

Table 22. Snapshot Efficiency Tool Inputs: Fresno, Part 1

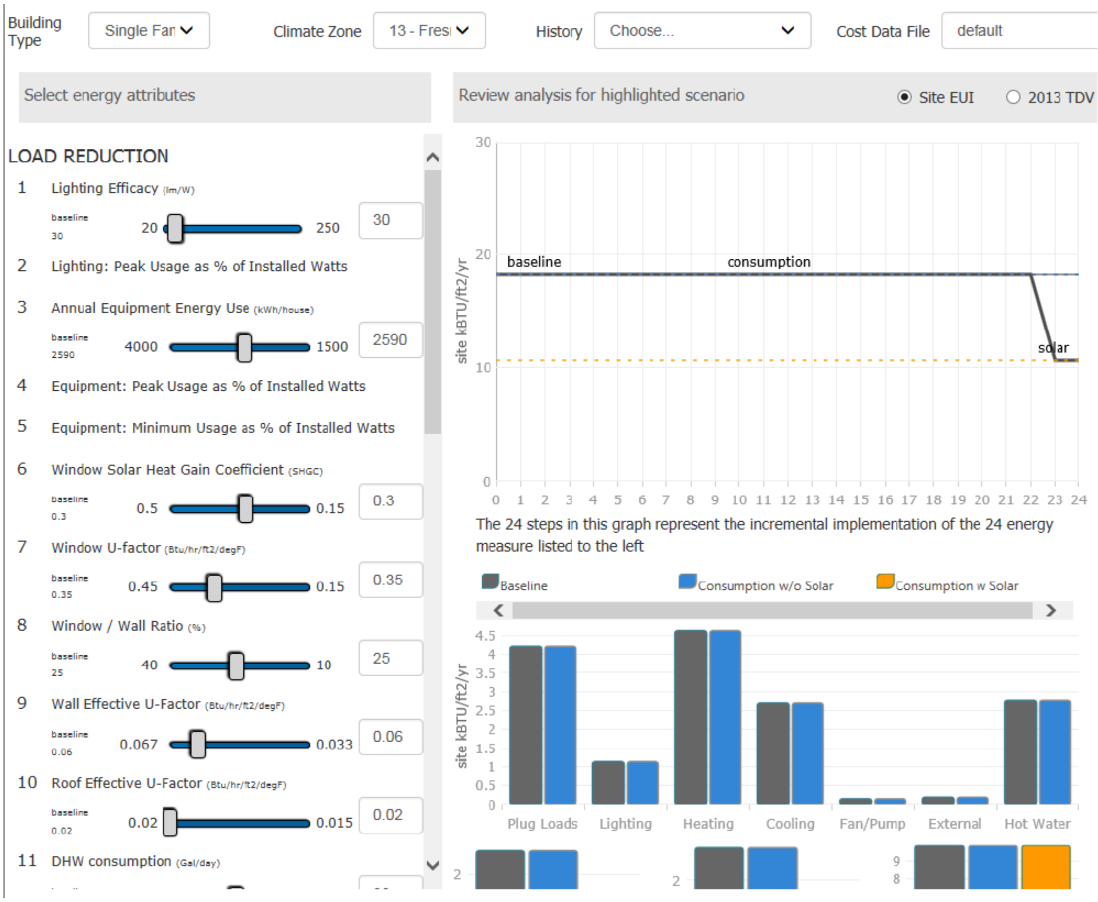


Table 23. Snapshot Efficiency Tool Inputs: Fresno, Part 2

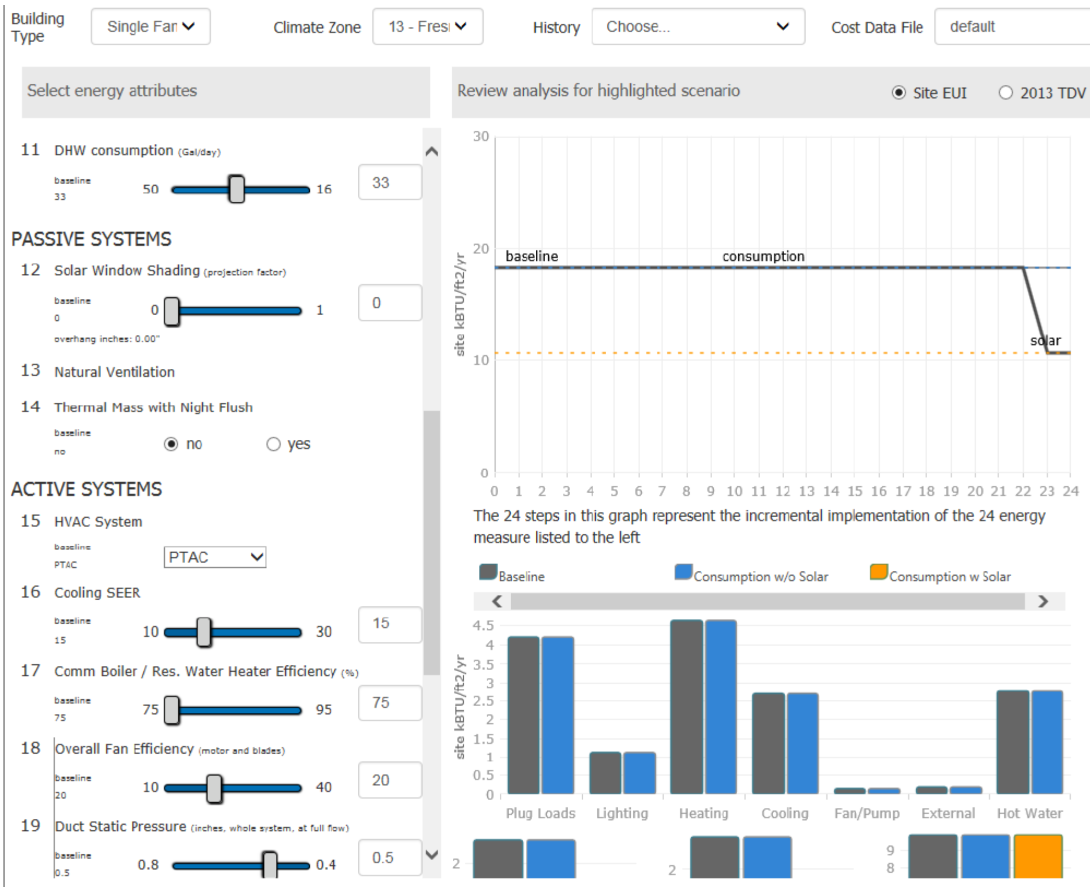
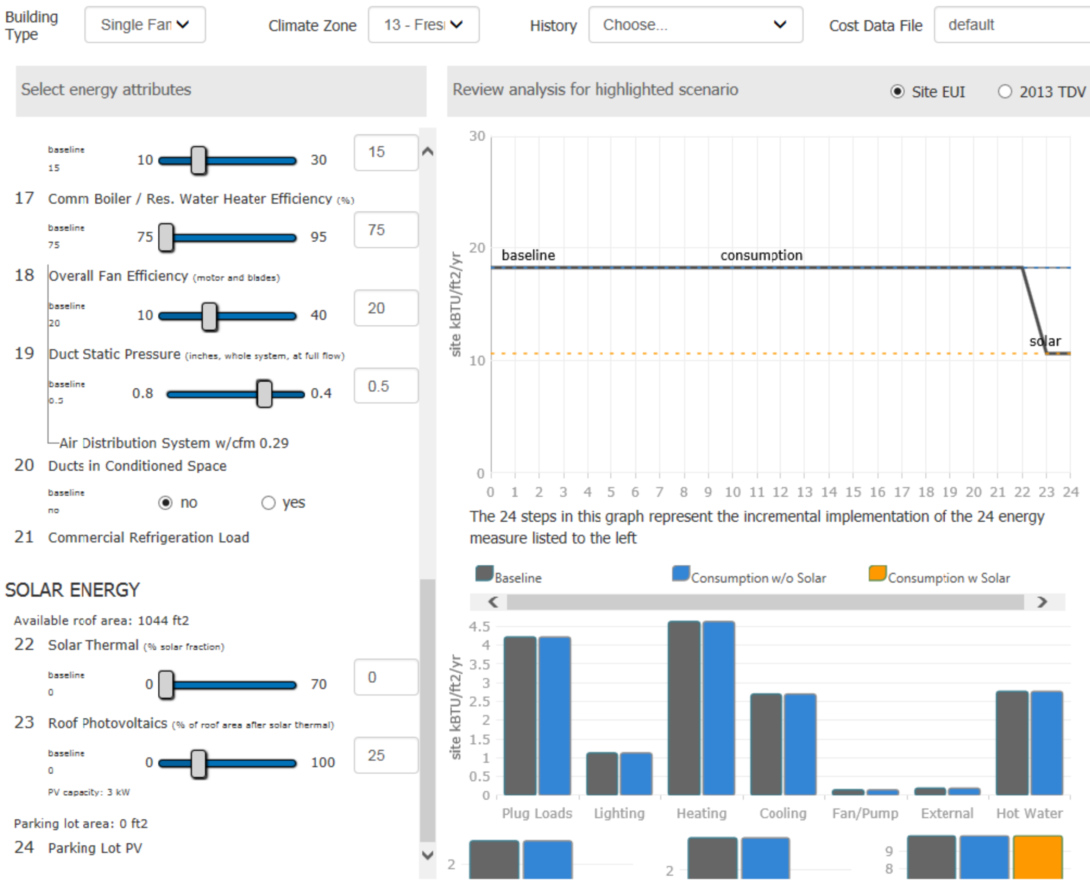


Table 24. Snapshot Efficiency Tool Inputs: Fresno, Part 3



Appendix E - Snapshot Efficiency Tool Inputs: Oakland

Table 25. Snapshot Efficiency Tool Inputs: Oakland, Part 1

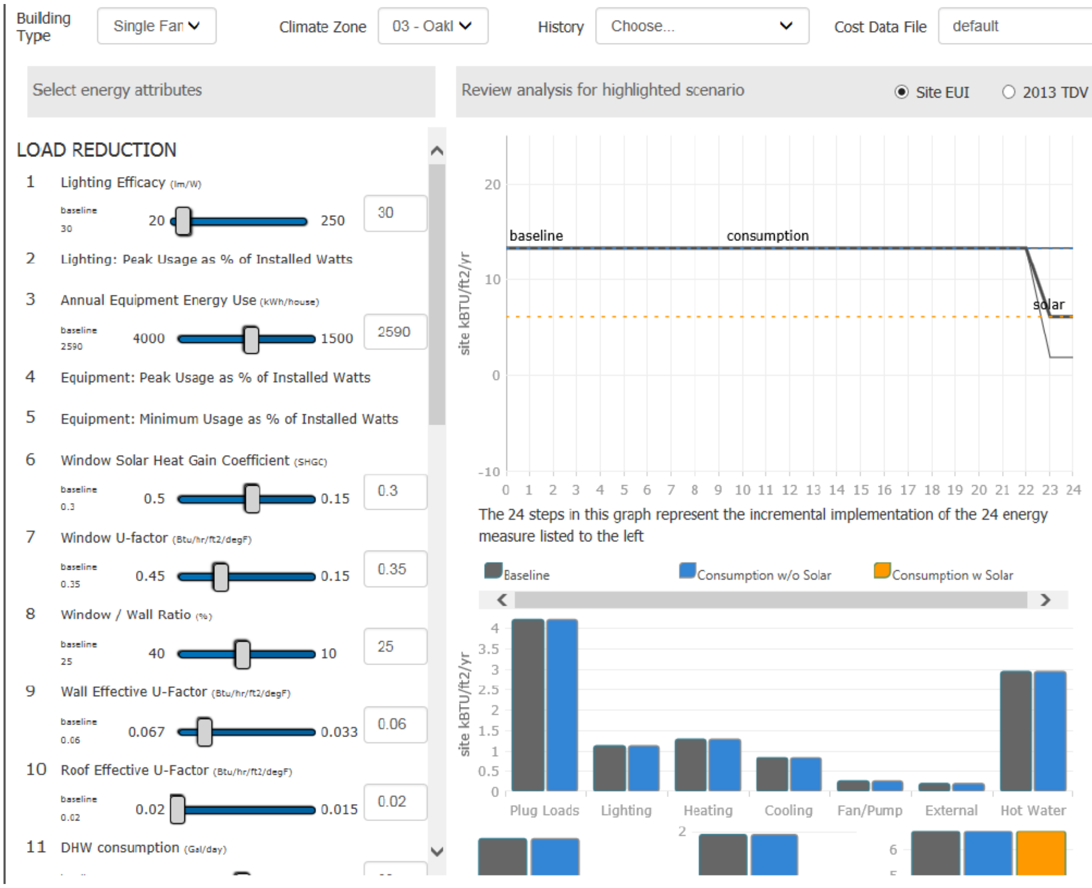


Table 26. Snapshot Efficiency Tool Inputs: Oakland, Part 2

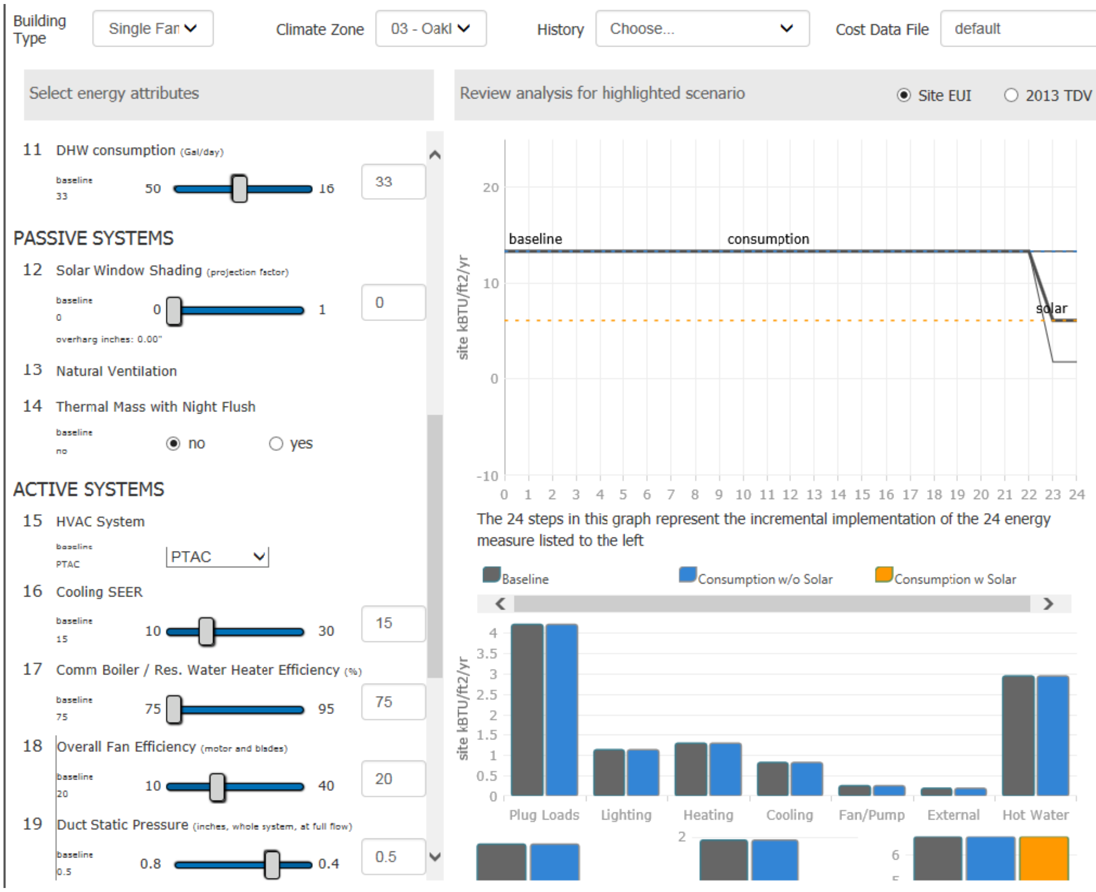
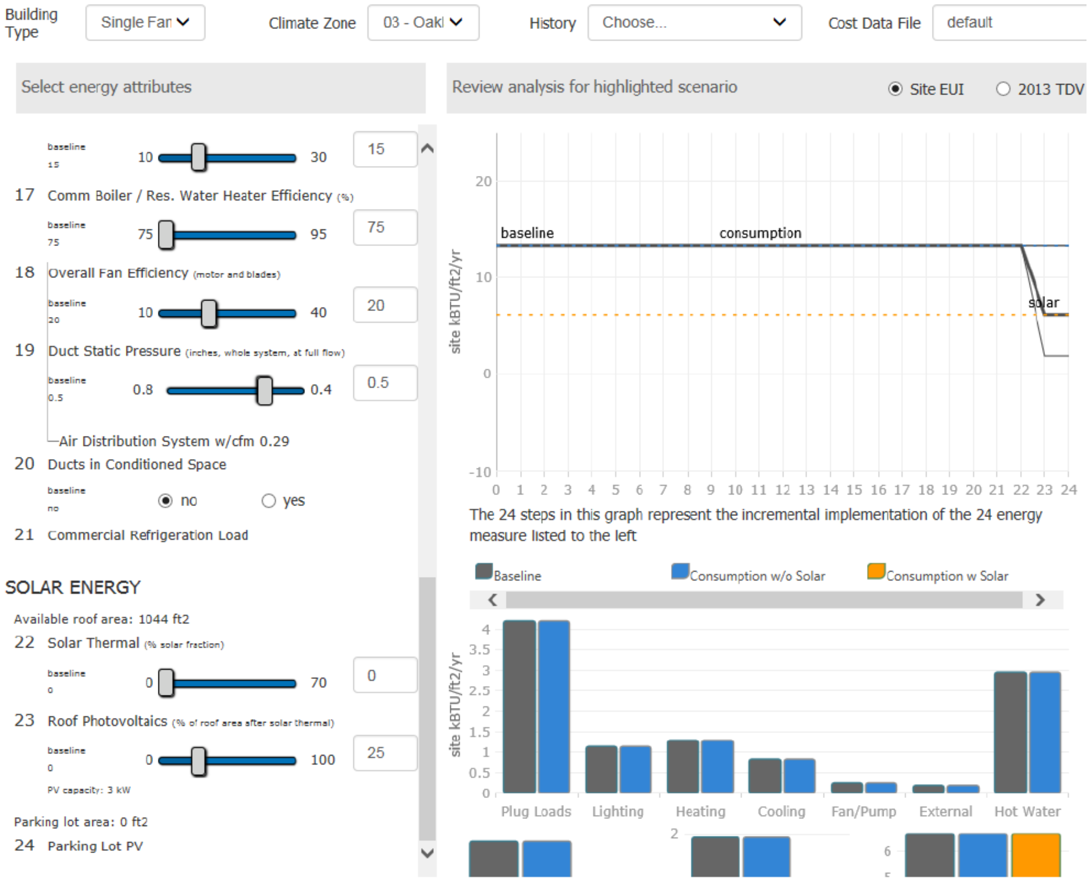


Table 27. Snapshot Efficiency Tool Inputs: Oakland, Part 3



Appendix F - Cost Benefit Analysis Calculation Methodology

F.1 Group A Calculation Methodology

Table 28. Group A of Cost-Benefit Value Streams

Group	Value Stream	SCT	TRC	RIM	PACT	PCT
A	Avoided Capacity	Benefit	Benefit	Benefit	Benefit	

Avoided capacity costs are treated as a benefit under all cost tests, except for the PCT because they do not affect the customer. These costs refer to avoided or deferred infrastructure investments such as power plants and transmission and distribution lines, as well as costs associated with CO_2 emissions and Renewable Portfolio Standard (RPS) compliance. In this analysis, as indicated in Table 14, the avoided capacity costs are expressed in units of "$/kW-yr" and are scaled by the demand savings resulting from storage (EV or stationary) discharging in response to DR events.

These avoided costs must be discounted to accurately capture the benefits of DR per the 2016 California DR cost-effectiveness protocols authorized by the CPUC[102]. The demand savings are based on the difference between the baseline scenario (non-DR participant) and test case (DR participant) storage discharge to the home during high system peak hours, subject to the availability of the storage (EV or stationary) to provide that service. There are negligible avoided capacity costs associated with the outage scenario in this analysis because an outage is only assumed to occur for a maximum of 2 hours per year. The present value of avoided capacity costs taken over the technology's measure lifetime is the final value used in the benefit to cost ratio calculation.

Table 14 summarizes the data requirements for quantifying the avoided capacity benefits, along with the sources used to obtain the data for the analysis. The measure lifetime and discount rate apply to all value stream groups in the analysis, yet are only detailed in this table for simplicity.

Table 29. Group A Value Stream Data Requirements

Data	Units	Source[103]	Notes
Avoided Cost of Capacity	$/kW-yr	E3 avoided cost calculator released September 29, 2017	Generation, transmission, and distribution values of firm capacity delivered to the market.
Customer A Factor (Availability)	%	PG&E assumption	The A factor for a single customer is different than the A factor for a program. PG&E's assumption is that stationary storage is always available for event participation, while an EV of any given customer is only available part time.
Program-Avoided Cost Discount Factors (A-G Factors)	%	PG&E: *2018-2022 Demand Response Programs, Pilots and Budgets Prepared Testimony*, January 17, 2017	Based on PG&E's CBP—see 2016 DR protocols for detail on discount factor definitions.
Baseline and Test Hourly	kW/hour	EV load shape and consumption assumptions derived from:	Test event profile based on EV load shape during event hours, whereby the EV is no

[102] California Public Utilities Commission, "2016 Demand Response Cost-Effectiveness Protocols": http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=11573
[103] Sources for each item are available in the data library.

Data	Units	Source[103]	Notes
Load for DR Event Days		• NREL CEC EV Infrastructure Projection Tool (EVI-Pro), Standard Home Dominant Scenario • US DOE *EV Project Electric Vehicle Charging* Infrastructure Report • Single-family home consumption profile from Arup's Snapshot Efficiency Tool • Roundtrip efficiency of charger from *Measurement of Power Loss during Electric Vehicle Charging and Discharging*, May 2017	longer charging and this energy needs to be made up later.
DR Event Timing	Hours of Day	Cpower: Demand Response in California, CBP[104]	Number of event hours based on average CBP hours per event reported for PG&E from 2013 to 2015. Hours of day selected by assuming events/outages that a battery can contribute to begin in the evening, as PV loads are high enough to sustain events/outages during the middle of the day.
Discount Rate	%	PG&E: *2018-2022 Demand Response Programs, Pilots and Budgets Prepared Testimony*, January 17, 2017	The analysis used the after tax WACC (7%) and the societal discount rate (5%) for the SCT.
Measure Lifetime	Years	Navigant Research Residential Energy Storage Database	Lifetime was based on standard 10-year manufacturer warranty.

F.2 Group B Calculation Methodology

Table 30. Group B of Cost-Benefit Value Streams

Group	Value Stream	SCT	TRC	RIM	PACT	PCT
B	Decreased Energy Supply Cost	Benefit	Benefit	Benefit	Benefit	
	Customer Bill Reductions			Cost		Benefit

Energy savings are treated as a benefit under all cost tests. Under the SCT, TRC, RIM, and PACT, they represent decreased supply costs, valued using avoided energy costs available at an annual, hourly level and are expressed in units of "$/kWh". Under the PCT, energy savings represent customer bill savings, valued using TOU customer retail rates. In this analysis, both the avoided energy supply costs and customer retail rates were scaled using the 8,760 energy savings resulting from EV discharging in response to DR events and islanding during a grid outage.

During a DR event, energy savings occur by powering the home using energy from the EV instead of the grid. The analysis also assumes that this energy needs to be made up later, so there is some increased energy use associated with doing this because of the charger's roundtrip efficiency losses. Whether

[104] CPower Energy Management, "Demand Response in California: The Capacity Bidding Program," (presentation), http://cpowerenergymanagement.com/wp-content/uploads/2016/11/CAISO_CBP-Web-Download_2.pdf.

there is an increased cost for this energy depends on the price differences expressed in TOU rates. Similarly, there is increased cost and energy use associated with recharging the EV after an outage event. The present value of these value streams taken over the technology's measure lifetime is the final value used in the cost-benefit ratio calculation.

Table 33 summarizes the data requirements for quantifying the avoided energy benefits, along with the sources used to obtain the data for this analysis.

Table 31. Group B Value Stream Data Requirements

Data	Units	Source[105]	Notes
Avoided Cost of Energy	$/kWh	E3 avoided cost calculator released on September 29, 2017	Average of Oakland and Fresno climate zones
Retail Rate	$/kWh	2017 GRC Phase II testimony	E-TOU Option B
Baseline and Test Hourly Load for DR Event Days	kW/hour	EV load shape and consumption assumptions derived from: • NREL's CEC EV Infrastructure Projection Tool (EVI-Pro), Standard Home Dominant Scenario • US DOE EV Project Electric Vehicle Charging Infrastructure report • Single-family home consumption profile from Arup's Snapshot Efficiency Tool • Roundtrip efficiency of charger from *Measurement of Power Loss during Electric Vehicle Charging and Discharging,* May 2017	Test event profile based on EV load shape during event hours, whereby the EV is no longer charging and this energy needs to be made up later.
DR Event Timing	Hours of Day	Cpower: Demand Response in California, CBP[106]	Number of event hours based on average CBP hours per event reported for PG&E from 2013 to 2015. Hours of day selected by assuming events/outages that a battery can contribute to begin in the evening, as PV loads are high enough to sustain events/outages during the middle of the day.
Outage Event Timing	Hours of Day	PG&E Electric reliability reports (SAIDI/SAIFI scores)[107]	Number of DR event hours based on average CBP hours per event reported for PG&E from 2013 to 2015. Hours of day for both DR events

[105] Sources for each item are available in the data library.
[106] CPower Energy Management, "Demand Response in California: The Capacity Bidding Program," (presentation), http://cpowerenergymanagement.com/wp-content/uploads/2016/11/CAISO_CBP-Web-Download_2.pdf.
[107] Pacific Gas and Electric Company, "Learn About PG&E Reliability Reports," *Pacific Gas and Electric Company,* 2017, https://www.pge.com/en_US/residential/outages/planning-and-preparedness/safety-and-preparedness/grid-reliability/electric-reliability-reports/electric-reliability-reports.page.

Data	Units	Source[105]	Notes
			and outages selected by assuming events/outage that a battery can contribute to begin in the evening, as PV loads are high enough to sustain events/outage during the middle of the day. Analysis assumes that the whole outage occurs in one event on a summer weekday.

F.3 Group C Calculation Methodology

Table 32. Group C of Cost-Benefit Value Streams

Group	Value Stream	SCT	TRC	RIM	PACT	PCT
C	Customer Reliability Improvements	Benefit	Benefit			Benefit

Customer reliability improvements are treated as a benefit under most of the cost tests considered in this analysis. It is a benefit exclusively associated with reduced outage events and hours, subject to same availability constraints detailed in the capacity impacts calculation. It is monetized using a value of service reliability expressed in units of “$/kWh”. The present value of this value stream taken over the technology’s measure lifetime is the final value used in the benefit to cost ratio calculation.

Table 35 summarizes the data requirements for quantifying customer reliability improvements, along with the sources used to obtain the data for this analysis.

Table 33. Group C Value Stream Data Requirements

Data	Units	Source[108]	Notes
Outage Event Timing	Hours of Day	PG&E Electric reliability reports (SAIDI/SAIFI scores)[109]	Hours of day for both DR events and outages selected by assuming events/outage that a battery can contribute to begin in the evening, as solar PV loads are high enough to sustain events/outage during the middle of the day. Analysis assumes that the whole outage occurs in one event on a summer weekday.
Customer Reliability Impacts from Prevented Outages	$/kWh	2015 LBNL *Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States* report	N/A

F.4 Group D Calculation Methodology

Table 34. Group D of Cost-Benefit Value Streams

Group	Value Stream	SCT	TRC	RIM	PACT	PCT
D	Customer O&M Costs	Cost	Cost			Cost
	Customer Capital Costs	Cost	Cost			Cost

Customer costs associated with purchasing V2H technology are treated as costs under the cost tests that include the customer perspective. These costs consist of a one-time upfront purchase cost and annual maintenance cost over the lifetime of the technology. This analysis only includes the incremental cost of purchasing a bi-directional charger and/or stationary storage because customers are already assumed to have an EV in the baseline scenario. The cost used for purchasing the bi-directional charger was $900, while the installation cost was $1,500. The costs assumed that buyers would choose a non-networked level 2 charger and would need to upgrade to a new networked unit.

The installation cost assumption may be conservative, but is likely reasonable as some users will not have had a pre-existing level 2 charger, or may have chosen a lower power rated charger leading to a need for more installation work. There are negligible O&M costs associated with cycling the EV battery in this analysis because the use cases PG&E is testing do not call for multiple cycles per day. It is also assumed the vehicle has a battery thermal management system. Therefore, unless there is high cycling

[108] Sources for each item are available in the data library.

[109] Pacific Gas and Electric Company, "Learn About PG&E Reliability Reports," *Pacific Gas and Electric Company,* 2017, https://www.pge.com/en_US/residential/outages/planning-and-preparedness/safety-and-preparedness/grid-reliability/electric-reliability-reports/electric-reliability-reports.page.

and full use of the SOC allowable multiple times on a per day basis, there would be little impact on O&M.

In the case of the stationary storage scenario, the upfront $6,200[110] cost of the system includes all O&M costs (software licenses, updates) when purchased directly from the manufacturer, and would require a $2,000 installation fee. The installation fee for the stationery storage system may vary based on a number of technical and infrastructure scenarios, but the conservative cost of $2,000 assures all foreseen costs would be included.

Table 37 summarizes the data requirements for quantifying customer costs, along with the sources used to obtain the data for the analysis.

Table 35. Group D Value Stream Data Requirements

Data	Units	Source[111]	Notes
O&M of Charger and Stationary Storage, as well as O&M Impacts from EV Discharge	$/year	**Charger/EV battery:** NREL's 2015 *Impact of Fast Charging on Life of EV Batteries* report[112] **Stationary storage:** Commercially available product data from vendor's website	**Charger/EV battery:** No O&M costs associated with cycling the battery because the use cases tested do not call for multiple cycles per day **Stationary storage:** Product pricing data includes all O&M costs when purchased directly from vendor
Customer Costs for Installing Bi-directional Charger	$/charger	**Equipment cost:** • *EV:* Based on the Clipper Creek HCS-50P charger model • *Stationary storage:* Based on measure characterization from Navigant project database **Installation cost:** • *EV:* HomeAdvisor website's "How Much Does It Cost to Install an Electric Vehicle Charging Station?" article on the 2017 Cost to Install an Electric Vehicle Charging Station page113 • *Stationary storage:* Based on measure characterization Navigant performed for a different client	**Baseline:** Level 2 charger without communication, EV, PV, inverter, critical panel **Test case:** Stationary storage SEP 2.0-capable; bi-directional SEP 2.0-capable Level 2 charger (hypothesized because DC charger not cost-viable in the residential market)

[110] Cost reflects a 3-bedroom house, critical panel only, 14 kWh battery, and can utilize 6.4 kW of installed solar.
[111] Sources for each item are available in the data library.
[112] Jeremy Neubauer, et al., "Impact of Fast Charging on Life of EV Batteries," (presentation, KINTEX, Korea, May 3-6, 2015), https://www.nrel.gov/docs/fy15osti/63700.pdf.
[113] Home Advisor, "How Much Do Electric Vehicle Charging Stations Cost to Install at Home," *Home Advisor*, http://www.homeadvisor.com/cost/garages/install-an-electric-vehicle-charging-station/.

F.5 Group E Calculation Methodology

Table 36. Group E of Cost-Benefit Value Streams

Group	Value Stream	SCT	TRC	RIM	PACT	PCT
E	Incentives Paid to Aggregator			Cost	Cost	
	Incentives from Aggregator to Customer					Benefit
	Customer Value of Service Lost (Mobility)	Cost	Cost			Cost

Incentive payments are treated as costs, benefits, or a transfer payment depending on the test being used to assess cost-effectiveness and are exclusive to the DR use case. Under the RIM test and PACT, which represent the ratepayer or utility perspective, they are treated as incurred costs. These costs represent the full payment the utility makes to a third-party aggregator for providing DR services. Under the PCT, which represents the customer perspective, they are treated as benefits. These benefits typically only include a portion of the payment the third-party aggregator receives from the utility based on a contractual agreement between the aggregator and the customer. Under the SCT and TRC, both the utility and customer perspectives are represented, so they cancel out and are not included in the cost-benefit ratio calculation.

Cost-effectiveness frameworks for DR programs typically also consider participant transaction costs, or the hassle factor associated with participating in DR events. It is assumed that these costs are less than the incentives participants receive for them to be willing to enroll in a program. These costs are generally not well understood in the industry. This analysis assumes that the participant transaction costs are worth 10% of the financial incentives received. Finally, this analysis also considers the impact of lost or delayed mobility to a customer during a DR event. Assuming customers can choose to not participate in a DR event if they need to travel, this impact is zero. This also assumes that the third-party aggregator acquires sufficient participants to ensure 100% compliance with DR event calls. The present value of the incentive streams described above taken over the technology's measure lifetime are the final values used in the cost-benefit ratio calculation.

Table 39 summarizes the data requirements for quantifying customer incentives and transaction costs, along with the sources used to obtain the data for the analysis.

Table 37. Group E Value Stream Data Requirements

Data	Units	Source[114]	Notes
Impact to Customer of Lost Mobility and/or Mobility Delay during EV Discharge	$/hour	PG&E assumption	Impact to customer of lost mobility and/or mobility delay during EV discharge. Assume that customers do not participate in a DR event if they need to travel, assuming the aggregator acquires more participants than needed to ensure 100% compliance with event calls.
Customer Incentives Paid by Utility for EV Discharging	$/kW/month, $/kWh	**Capacity payment:** PG&E: *2018 - 2022 Demand Response Programs, Pilots and Budgets Prepared Testimony*, January 17, 2017 **Energy payment:** Average CAISO Locational Marginal Price (LMP) in 2017 during CBP eligible hours	Based on PG&E's CBP. Table 2-2 of PG&E's 2018 - 2022 DR program application states that the energy payment for the CBP program is the pass-through of the wholesale energy settlement.
Portion of the Incentives an Aggregator Distributes to Participating Customers	%	PG&E assumption	This is a closely held trade secret with no publicly available source. The model will treat this as a sensitivity to determine the significance of this input.
Transaction Costs Associated with Participating in Called DR Events	$/kW, $/event	PG&E assumption	This input is uncertain and subject to sensitivity analysis.

F.6 Group F Calculation Methodology

Table 38. Group F of Cost-Benefit Value Streams

Group	Value Stream	SCT	TRC	RIM	PACT	PCT
F	Utility O&M Costs	Cost	Cost	Cost	Cost	
	Utility Capital Costs	Cost	Cost	Cost	Cost	
	Utility Admin Costs	Cost	Cost	Cost	Cost	

Costs incurred by the utility to administer a DR program are considered in all tests except for the PCT, which assesses cost-effectiveness exclusively from the customer perspective. These costs include annual administrative costs associated with running the program, along with annual O&M costs associated with marketing, education, and training. Capital costs incurred by the utility to set up a DR program are also typically considered in the cost-effectiveness test. However, in this analysis, it is assumed that the customer bears all equipment and installation costs. This is consistent with the third-party administered CBP program structure. The present value of these utility costs taken over the technology's measure lifetime is the final value used in the cost-benefit ratio calculation.

[114] Sources for each item are available in the data library.

Table 39 summarizes the data requirements for quantifying utility costs, along with the sources used to obtain the data for the analysis.

Table 39. Group F Value Stream Data Requirements

Data	Units	Source[115]	Notes
Utility Costs for Administering Program	$/MW/year	Navigant Consulting Database	N/A
Utility Annual Costs for O&M	$/MW/year	Navigant Consulting Database	EVSE O&M, education, and awareness promotion cost
Utility Costs for Service Upgrade to Accommodate bi-directional EVSE	$/charger	Not applicable	One-Time Utility costs for upgrading customer service for bidirectional EVSE. [116]

[115] Sources for each item are available in the data library.

[116] One-Time Utility costs for upgrading customer service for bidirectional EVSE. Assuming zero as CPUC D.16-06-11, Ordering Paragraph 1, extended to June 30, 2019 the "common facility treatment", or exemption, for PEV load-related costs in excess of the residential allowance to be recovered through electric distribution rates; the amount for which to date has been considered "immaterial" by the CA IOUs (R1311007 - Joint IOU Electric Load Research Report, 12/30/16). This category could also include the cost of a software license for participating in DR should a program include that provision.

Appendix G - Customer Survey - Electric Vehicle to Home Concept Test Final Report

Background

PG&E is exploring the viability of a clean energy system powering a home in the case of a power outage or during a demand response event. As part of a larger Assessment, the Grid Innovation team asked PG&E's Customer Insights and Strategy to explore the idea with current EV Owners. The purpose of the study was to gauge EV Owners' interest in the concept, and assess the current market potential of the new technology.[117]

Findings

Interest in the technology is very high among EV Owners. Absent any discussion of price, more than half said they would be very interested in the technology. However, interest in the concept significantly declines when the estimated price (about $4,500[118]) is known. Interest in the technology remains low even with the additional benefits of allowing them to manage their energy load. With both EV Owners and Non-EV Owners, only about one in ten are interested in the technology at the $4,500 to $6,000 price points. Those still interested tend to be customers in the highest income ranges ($200K and above) and are therefore less price sensitive.

We estimate the optimal price to be around $800, with the optimal range anywhere from $650 to $1,000. Beyond this point, consumers don't feel that the frequency of power outages justifies the expenditure. The research suggests that a price in the $650 to $800 range would garner a fairly robust level of interest, but begins to drop dramatically much beyond the high end of the optimal range.

Respondents viewed the technology primarily more as an emergency preparedness tool and/or a way to retain power during an outage—and less as a way for them to save money on their bills. While most customers have experienced multiple power outages, they tend to be infrequent and of short duration. As a result, relatively few (about one in ten) are very concerned about them.

There is a potential marketing opportunity for EV manufacturers to appeal to a small group of potential EV consumers. About 12% said they would be much more likely to consider purchasing an EV if this technology were available.

Conclusions

The technology's adoption is hampered both cost and by a general lack of concern with experiencing outages. For most, the risk of an outage does not justify the additional expense of acquiring this technology at this time. There is definitely potential for this technology down the road, but only if customers' out-of-pocket expenses can be dramatically reduced. At present, however, the gap between actual cost and marketable cost is simply too wide.

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[117] Concept tests are useful in gauging likely consumer interest in proposed new ideas or actual products and services. Stated percentages should be interpreted as expressions of magnitude, not as having exact 1:1 relationships between interest and ultimate adoption.

[118] Cost estimate used in the customer survey for a V2H system includes a hypothesized bi-directional charger and installation cost of $2,400 (Table 10) as well as estimated critical panel costs (transfer switch, panel equipment, switch box) and installation of $2,100. Critical panel costs are hypothesized based on anecdotal market quotes obtained by PG&E for the purposes of the customer survey. There is a high degree of uncertainty in the estimate due to the lack of a commercially available bi-directional charger, and therefore, a lack of procurement and installation experience by the supply chain for a V2H system.

EV-to-Home Concept Test

At-A-Glance

Product Interest	
Product interest is very high (Pre-Price), but significantly declines once the price is known	
Interest in the technology is very high. Prior to any discussion of price, 54% of EV Owners said they were “very interested” in the technology. However, interest declined to only 9% once a price point of $4,500 was established. Adding enhanced features for a slightly higher price did not alter interest in the product.	
	% Very Interested
Pre-Price	54%
Basic EV-to-Home Charging @ $4,500	9%
Enhanced (EV-to-Grid) Product Features @ $6,000	11%

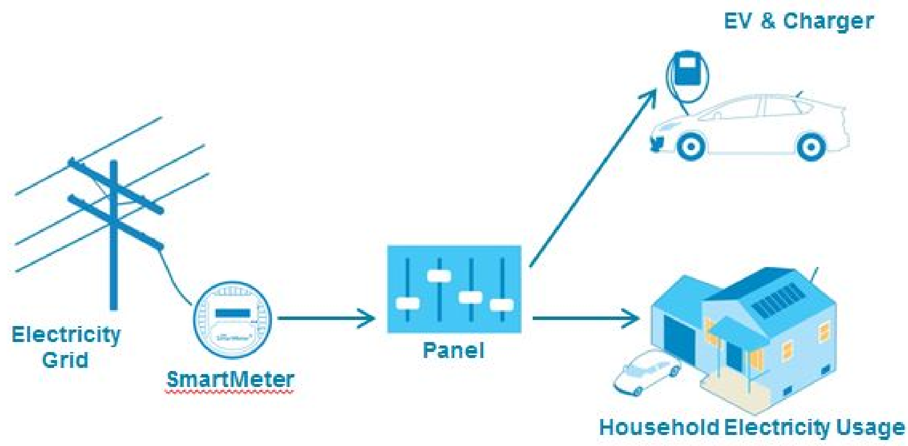
Barriers to Adoption			
Price and a low level of concern with outages are the most sigificant barriers to adoption			
The optimal price tag would need to be no more than about $1,000, including installation, before EV Owners would seriously consider adopting the technology. Another barrier to to adoption is the general lack of concern about outages. While most have experienced multiple outages, relatively few are very concerned about them.			
Barrier 1: Price		**Barrier 2: Low Concern with Outages**	
Current Price	$4,500	Experienced Multiple Outages	65%
Optimal Price	$800	Very Concerned About Outages	12%

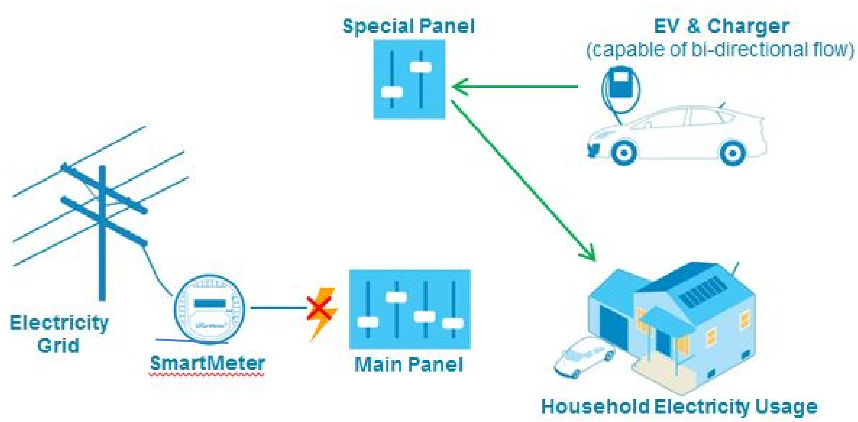
Non-EV Owner Interest	
A small number Non-EV Owners said they would be much more likely to consider purchasing an EV if the new technology was available	
Despite the cost, a small percentage (12%) of Non-EV owners said this new technology would make them *much more likely* to consider purchasing an electric vehicle in the future.	
Much More Likely	12%
Somewhat More Likely	42%

Greatest Appeal (Positioning)	
The technology is viewed primarily as a way to retain power during an outage and secondarily as a way to save money on their bill	
With both EV and Non-EV owners, the greatest appeal of this technology was its ability to allow them to retain power during an outage. Saving money on their bill and becoming less dependent on the grid were secondary considerations.	
Emergency Prepardness / Retaining Power During an Outage	54%
Save Money on Bill / Earning incentives through PG&E programs	23%
Be Less Dependent on the Grid	15%

FULL TEST RESULTS

EV Owners were shown the following images describing the EV-to-Home technology. They were then asked a series of questions about their interest in the concept.

NORMAL SETUP
Houses typically have one electrical panel. All household electricity use, including EV charging, is powered by circuits connected to the panel, and flows in one direction—out from the panel.


NEW SETUP
A new set up would enable an electric vehicle (EV) to provide backup power to your house in the event of a power outage. A special panel would be installed to allow your EV's battery to feed back to your house during a power outage. This would allow you to retain power to preselected circuits in your home (e.g. refrigerator, some lights, medical equipment, etc.), for several hours or even several days, depending on the battery.


Overall Interest

Interest in the technology is very high among EV Owners. Absent any discussion of price, more than half (54%) said they would be very interested in the technology.

We would like to ask you some questions concerning an emerging technology that PG&E is investigating. It will soon be possible for those with electric vehicles to use their EV's battery to power their homes directly (off-grid) for several hours or even several days, depending on the capacity of the battery. Q9. Putting aside the cost issue for now, how **interested** are you in being able to power your residence from your electric vehicle's battery for a short period of time, for example, when there is a power outage?			
Base: EV Owner (n=441)	**Very Interested**	**54%**	
	Somewhat	35%	
	Not interested	9%	
	Not sure	2%	

However, interest in the concept significantly declines when the estimated price—about $4,500—is known.

- Interest among EV Owners drops from 54% to just 9% once the price is known
- There is no significant difference in interest among EV and Non-EV owners

The basic idea is that during a power outage you could use your electric vehicle's battery to charge directly to your home for several hours, or a few days, depending on your battery. This would have the following benefits:

- Provide emergency power to part of your house in the event of an outage
- If you have Solar panels, they could continue to generate through an outage

The average cost of the system is estimated to be, on average, around **$4,500**, including installation.

Q14. As described, how **interested** would you be in acquiring this technology for your home?

Base: Total Respondents	**Very**	**Somewhat**	**Neutral**	**Not Much**	**Not At All**	**Not Sure**
EV Owners *(n=441)*	9%	28%	13%	27%	22%	1%
Non-EV Owners *(n=2,045)*	13%	28%	15%	18%	22%	2%

At a cost of about $6,000, interest in enhanced features that allow EV Owners to manage load is low, and essentially unchanged from their interest in the basic feature described earlier.

- With both EV Owners and Non-EV Owners, only about 10% are very interested in this feature

The technology described above is only able to discharge electricity from the electric vehicle when disconnected from the grid.

With more sophisticated components you would be able to discharge electricity from your electric vehicle while still connected to the grid, allowing you to shift your electricity use from the grid and lower your bill. This would have the added advantages of…

- Flatten peaks/spikes from your usage to help lower your energy bill
- Earn incentives on programs which reward you for shifting energy to off-peak hours.

As well as…

- Providing emergency power to part of your house in the event of an outage
- If you have Solar panels, they could continue to generate through an outage

The average cost of this enhanced system is estimated to be, on average, around **$6,000**, including installation.

Q15. As described, how **interested** would you be in acquiring this enhanced version of the technology for your home?

Base: Total Respondents	**Very**	**Somewhat**	**Neutral**	**Not Much**	**Not At All**	**Not Sure**
EV Owners *(n=441)*	11%	21%	15%	25%	27%	1%
Non-EV Owners *(n=2,045)*	11%	24%	16%	20%	26%	3%

Although a relatively small percentage, there is nevertheless a potential opportunity for EV manufacturers.

- Despite the cost, about one in eight (12%) Non-EV Owners said they would be "*much more likely*" to consider purchasing an EV if this technology were available.

Q17. If this technology were available, how much more likely would you be to consider purchasing an electric vehicle?

Base: Non-EV Owner (n=2,045)		**Non-EV Owners**
	Much more likely	12%
	Somewhat more likely	42%
	Neither more nor less likely	36%
	Less likely	4%
	Not sure	5%

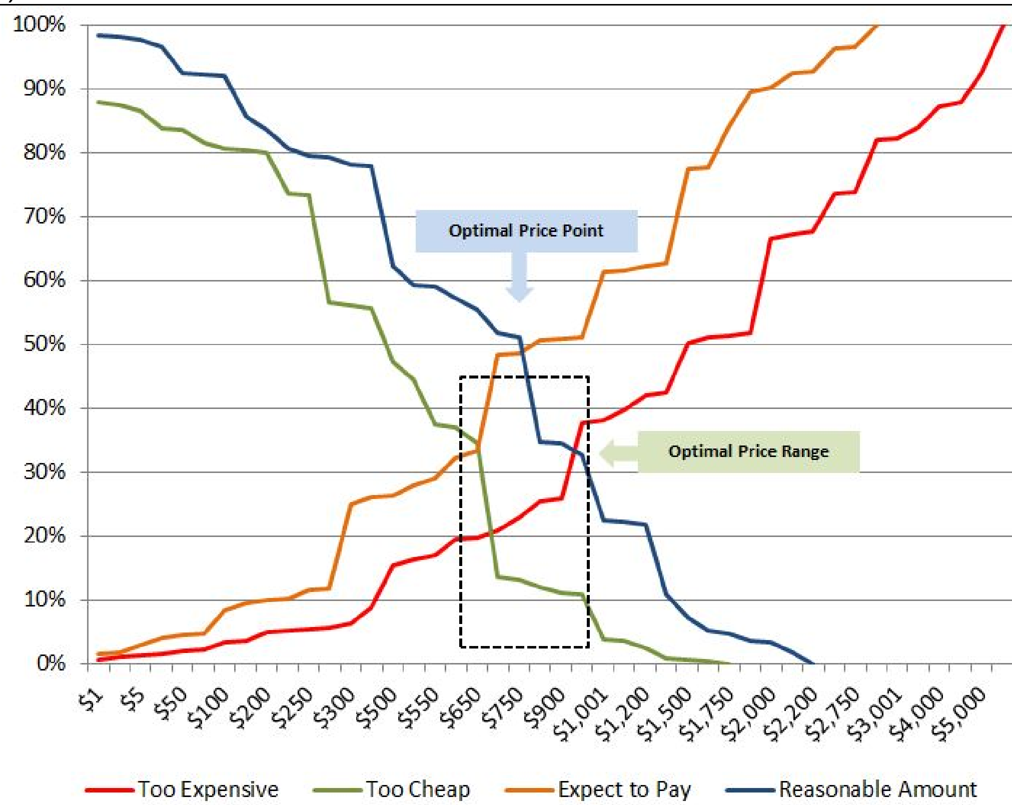
Optimal Price

We estimate the optimal price point for this product at about $800, with the optimal range from $650 to $1,000. Interest should be near pre-price levels at the optimal ($800) price point.

The cost of this new technology would require you to purchase the following components:

- A level 2 Electric Vehicle (EV) charger capable of bi-directional power flow
- A special panel
- Installation labor

*Q10. What would you **expect** to pay to have this system installed? Your best guess is fine.*
*Q11. What do you think would be a **reasonable** price to pay to have this system installed?*
*Q12. At what point would you consider this service to be **too expensive**?*
*Q13. At what point would you consider the price to be so **low** that you would be skeptical about it working properly?*
Base sizes vary



Concern with Outages

The greatest appeal of this technology is being prepared in case of an emergency and retaining power during an outage.

- Saving money on their bill is secondary consideration

Q16. What is the greatest appeal of this technology to you personally?			
	EV Owners	**Non-EV Owners**	**Total**
	(n=441)	*(n=2,045)*	*(n=2,486)*
Being more prepared in case of an emergency	30%	29%	29%
Retaining power during an outage	29%	24%	25%
Saving money on my electricity bill	18%	22%	21%
Being less dependent on the grid	14%	15%	15%
Earning incentives through PG&E programs	2%	2%	2%
Other	7%	9%	8%

While about two-thirds of all customers (63%) have experienced 2 or more outages in the past two years…

Q18. How many times in the past **two years** have you experienced an unexpected power outage at your home?		
Base: Total Respondents (n=2,486)		**Total**
	1	19%
	2	23%
	3	16%
	4	11%
	5 or more	13%
	None	11%
	Not Sure	7%

…Only about one in six (12%) are very concerned about outages.

Q19. How concerned are you about experiencing power outages in your home?		
Base: Total Respondents (n=2,486)		**Total**
	Very	12%
	Somewhat	35%
	Not too much	53%

EV Owner Profile

Nearly half (47%) have purchased their electric vehicle within the past 3 years.

Q4. How many years have you owned an Electric Vehicle?		
Base: EV Owners (n=441)	Less than 1 Year	16%
	1 year but less than 2 years	14%
	2 years but less than 3 years	17%
	3 years but less than 4 years	19%
	4 years but less than 5 years	14%
	5 or more years	19%

One in six (17%) own more than one electric vehicle.

Q5. How many different **plug-in electric** vehicles do you currently own for your personal household use?		
Base: EV Owners (n=441)	1	83%
	2	15%
	3 or More	2%

Nearly all EV Owners charge their vehicle at home.

Q6. Do you usually charge your Electric Vehicle at…?		
Base: EV Owners (n=441)	Both Home and Away	53%
	Home only	43%
	Away from Home only (work, public parking, etc.)	4%

On average, EV Owners leave their car plugged in at home for about 10 hours per day.

Q7. About how many hours per day is your car plugged in at home (whether or not it is charging while plugged in)		
Base: EV Owners who charge at home (n=421)		
	Median Number of Hours:	10.0
	Not Sure	8%

Nearly two-thirds of EV Owners said they use faster, Level 2 charging at home, which requires the installation (and additional cost) of a dedicated EV charger.

EV owners currently have two options for charging their electric vehicle at home: • Normal charging, using a standard electrical outlet (Level 1) • Faster charging, which requires installation of a dedicated EV charger (Level 2) Q8. Which of these charging options do you use at your primary residence?		
Base: EV Owners who charge at home (n=421)	Faster charging (Level 2)	62%
	Normal charging (Level 1)	37%
	Not sure	1%

About the Survey

The survey was conducted online using PG&E Customer Voice Online Forum, an opt-in panel of about 9,300 residential customers in PG&E service territory. Respondents were screened from EV ownership. EV Owners were given a slightly longer survey. The data collection period was from December 27, 2017 to January 4, 2018.

EV Ownership	Frequency	Percent
Owns EV	441	18%
Does Not Own EV	2,045	82%
Total	**2,486**	**100%**