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The Potential Electric Grid Benefits of Vehicle-to-Grid Technology in California

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The Potential Electric Grid Benefits of Vehicle-to-Grid Technology in California:

V2G shows high value for capabilities beyond one-way managed charging

Introduction

With electric vehicles (EVs) rapidly becoming more popular, and a need for flexible energy storage resources in the electric grid, the development of Vehicle-Grid Integration (VGI) technology has taken on a new urgency. VGI technology encompasses any technology that helps EVs to better integrate with the grid, including both management of charging and control of bi-directional charging and discharging. The practice of managing the 1-directional flow of power from the grid to vehicles, or V1G, is already being rolled out across California and in many places where EVs have become popular. V1G programs in California include San Diego Gas and Electric's *Power Your Drive*, EV specific retail tariffs from Southern California Edison, and the *Charge Forward* smart charging pilot program from Pacific Gas and Electric in collaboration with the automaker BMW.

Adding the physical capability for EVs to inject power from their batteries into the grid, commonly referred to as Vehicle-to-Grid or V2G, has the potential to deliver greater benefits to the electric grid than V1G. There are, however, significant barriers to widespread deployment of V2G, including the development of standards for information exchange, regulatory frameworks, and business models. These barriers are similar to those facing other distributed energy resources (DERs), but are even more complex due to the fact that vehicles are mobile

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and will need the flexibility to plug-in to a variety of electric vehicle service equipment (EVSE) and at a variety of locations to charge and discharge power.

Another key barrier to further development and deployment of V2G identified at the California Energy Commission's (CEC) recent VGI Roadmap Update Workshop is a lack of knowledge about the value that V2G can provide and what the most promising V2G use cases for capturing that value are. Without this knowledge, industry is hesitant to invest in developing and deploying V2G technology. As a part of California Energy Commission project 14-086 *Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability*, Energy and Environmental Economics, Inc. (E3) was tasked with quantifying the potential benefits of V2G technology to California's ratepayers across a variety of use cases. In this article, we'll share results and key insights from this work. We believe these results provide regulators and industry with critical information that will help to identify the best opportunities for V2G technology in California.

Modeling the electric grid benefits of V2G

Optimized Dispatch Using the CEC Solar + Storage Tool

To estimate the electric grid benefits of V2G, we conducted a case study covering several scenarios and use cases, between now and the year 2030. The case study was performed using the CEC Solar + Storage Tool, which was developed by E3. New EV specific modeling and dispatch optimization features were added to the tool, including the unique constraints that transportation creates for EVs used as DERs. The model optimizes a joint dispatch schedule for a group of EVs that plug-in at a common workplace during work hours and at separate homes during other times. For this study, we modeled a group of 5 vehicles,

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with each having a 60 kWh battery and a maximum charging and discharging power of 6.6 kW. We assumed that each vehicle has access to a V2G capable EVSE at both home and work.

The tool can model several VGI use cases. To create a baseline for determining the value of optimized EV dispatch, an “unmanaged” charging profile is generated. Under an unmanaged charging strategy, whenever an EV plugs in it is charged immediately at maximum power until full state of charge is reached. Dispatch can then be conducted in either V1G mode or V2G mode so that the incremental benefits of these technologies can be determined. V1G and V2G dispatch can be optimized from the perspective of customers, to maximize their bill savings, or from the utility’s perspective to minimize the utility’s cost of supplying electricity, commonly known as the utility’s *avoided cost*. The charging and discharging dispatch can also be co-optimized with the sale of frequency regulation ancillary service (AS) to the grid.

A common concern about V2G technology is that discharging the vehicle’s battery will increase battery degradation and shorten the battery’s useful life in transportation. To reflect these concerns, the optimization model can penalize the discharge of energy from an EV’s battery to the grid and having a state of charge outside of a specified range. For this study, we chose penalties based on EV battery cycle life and cost of replacement and penalized states of charge outside the range of 30% to 95%.

V2G dispatch flexibility creates advantages over V1G

Optimized dispatches of EV charging and discharging created with the Solar + Storage tool demonstrate why V2G is a much more flexible resource than V1G. Figure 1 shows example optimized dispatches under V1G or V2G modes for a single vehicle that is plugged into the grid for 23 hours on a Saturday, making one late evening trip at 9pm. The utility avoided costs

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represent a typical early summer day in the future California electric grid where solar overgeneration causes negative mid-day energy market prices. As shown in figure 1, discharging in the morning gives the V2G vehicle more available battery capacity than the V1G vehicle to charge during the period of negative prices. The V2G vehicle can then discharge some energy from its fully charged battery in the high value evening hours, either before or after taking a trip. By absorbing excess solar generation through charging, the load of the V1G vehicle creates a benefit for the utility of $0.06 on this day. However, since the V2G vehicle is able to charge far more energy than the V1G vehicle mid-day and then also discharge to the grid at high value times, it creates a benefit of $1.96 for the utility. These values are absolute and not relative to other charging profiles.

An EV with V2G also has an advantage in capturing value during times with high energy prices or high generation and distribution capacity value. An EV with V2G will fill its battery and prepare to discharge as much energy as possible during times of high value, while an EV with V1G can only create value by shifting co-incidental charging load off of peak times. We can also notice from dispatch results that if a V1G vehicle rarely drives, and thus consumes relatively little energy, there is less load that can be shifted to periods of negative pricing and less value in managing its charging load. However, a V2G vehicle that mostly sits unused for transportation offers more scheduling flexibility and value to the utility as a DER than an EV that needs frequent and large amounts of energy for transportation.

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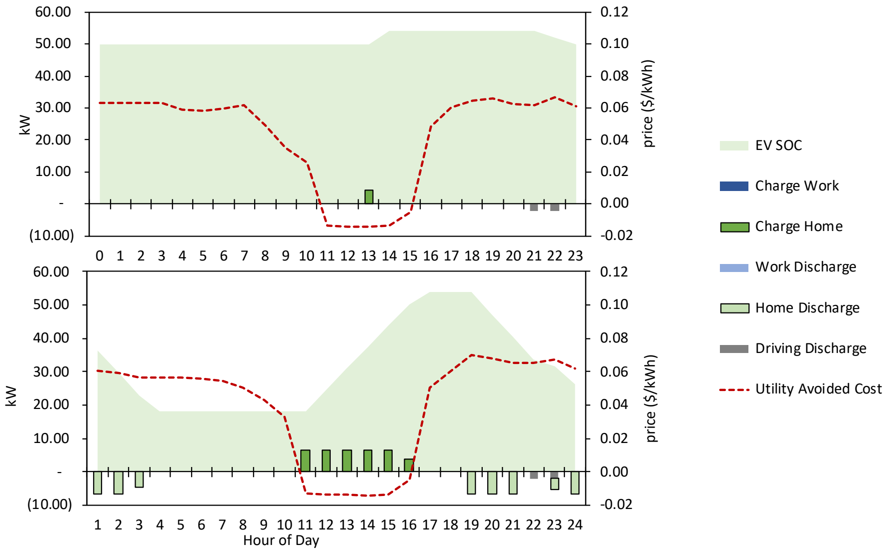
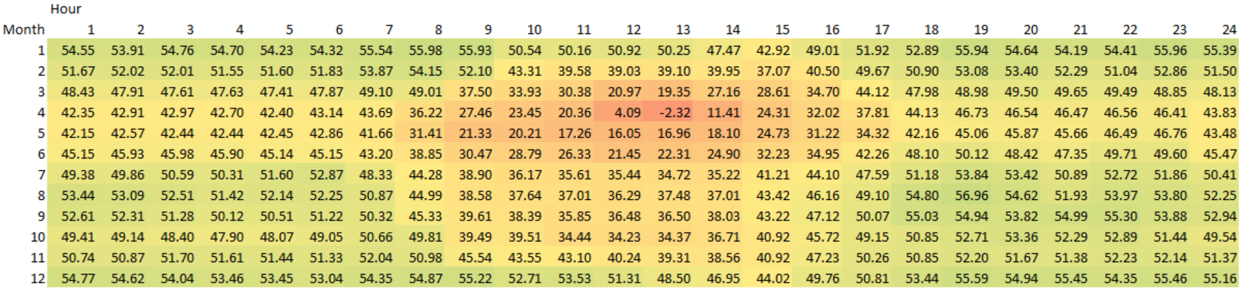
Figure 1. Example V1G and V2G Dispatch During Solar Overgeneration for a Single EV



Avoided Cost Value Streams

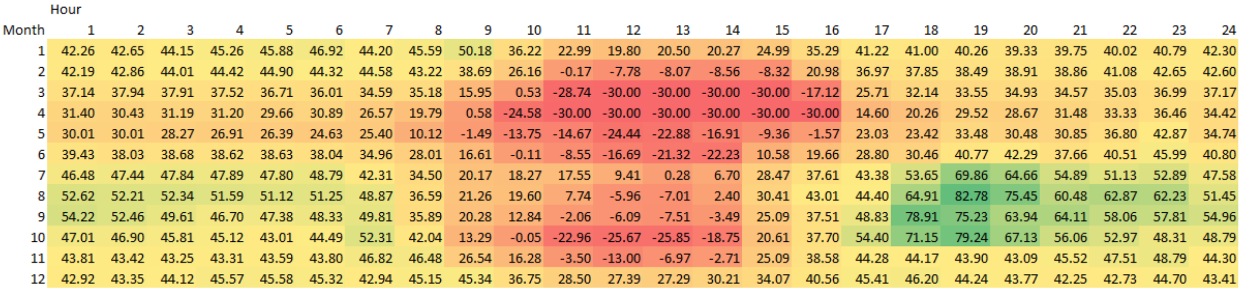
We considered two scenarios for evaluating VGI technologies: a base scenario and a high value scenario. The value streams that change between the base and the high value scenarios are energy and AS market prices, distribution network capacity value, and generation capacity value. AS revenues are not captured as an avoided cost like the other value streams in the study are, but it is modeled as a service that can be offered subject to market and physical constraints. Energy and AS market prices are based on CPUC Integrated Resources Planning (IRP) proceeding cases, and are estimated using production simulation. The base scenario aligns with the CPUC IRP reference case, which achieves roughly a 50% renewable portfolio standard (RPS) by 2030. This matches the 2030 goal of California's recently adopted law, SB 100. In our high value case, the electric grid achieves an 80% RPS by 2030. The effects of increasing renewable penetration on energy market prices are shown below in figures 2 and 3, with red indicating negative energy prices and green indicating high energy prices. In the high value scenario, negative mid-day energy prices are more pronounced throughout the year. Energy prices are generally lower in the high value scenario, with the exception of higher evening time energy prices in the fall. Since energy prices can be an opportunity cost to providing AS, we believe that AS market trends would follow the energy market trends in the high value scenario, causing lower mid-day AS prices and higher prices during fall evenings than current market conditions.

Figure 2: Average Hourly Energy Prices in 2030, Base Scenario



	Hour																							
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	54.55	53.91	54.76	54.70	54.23	54.32	55.54	55.98	55.93	50.54	50.16	50.92	50.25	47.47	42.92	49.01	51.92	52.89	55.94	54.64	54.19	54.41	55.96	55.39
2	51.67	52.02	52.01	51.55	51.60	51.83	53.87	54.15	52.10	43.31	39.58	39.03	39.10	39.95	37.07	40.50	49.67	50.90	53.08	53.40	52.29	51.04	52.86	51.50
3	48.43	47.91	47.61	47.63	47.41	47.87	49.10	49.01	37.50	33.93	30.38	20.97	19.35	27.16	28.61	34.70	44.12	47.98	48.98	49.50	49.65	49.49	48.85	48.13
4	42.35	42.91	42.97	42.70	42.40	43.14	43.69	36.22	27.46	23.45	20.36	4.09	-2.32	11.41	24.31	32.02	37.81	44.13	46.73	46.54	46.47	46.56	46.41	43.83
5	42.15	42.57	42.44	42.44	42.45	42.86	41.66	31.41	21.33	20.21	17.26	16.05	16.96	18.10	24.73	31.22	34.32	42.16	45.06	45.87	45.66	46.49	46.76	43.48
6	45.15	45.93	45.98	45.90	45.14	45.15	43.20	38.85	30.47	28.79	26.33	21.45	22.31	24.90	32.23	34.95	42.26	48.10	50.12	48.42	47.35	49.71	49.60	45.47
7	49.38	49.86	50.59	50.31	51.60	52.87	48.33	44.28	38.90	36.17	35.61	35.44	34.72	35.22	41.21	44.10	47.59	51.18	53.84	53.42	50.89	52.72	51.86	50.41
8	53.44	53.09	52.51	51.42	52.14	52.25	50.87	44.99	38.58	37.64	37.01	36.29	37.48	37.01	43.42	46.16	49.10	54.80	56.96	54.62	51.93	53.97	53.80	52.25
9	52.61	52.31	51.28	50.12	50.51	51.22	50.32	45.33	39.61	38.39	35.85	36.48	36.50	38.03	43.22	47.12	50.07	55.03	54.94	53.82	54.99	55.30	53.88	52.94
10	49.41	49.14	48.40	47.90	48.07	49.05	50.66	49.81	39.49	39.51	34.44	34.23	34.37	36.71	40.92	45.72	49.15	50.85	52.71	53.36	52.29	52.89	51.44	49.54
11	50.74	50.87	51.70	51.61	51.44	51.33	52.04	50.98	45.54	43.55	43.10	40.24	39.31	38.56	40.92	47.23	50.26	50.85	52.20	51.67	51.38	52.23	52.14	51.37
12	54.77	54.62	54.04	53.46	53.45	53.04	54.35	54.87	55.22	52.71	53.53	51.31	48.50	46.95	44.02	49.76	50.81	53.44	55.59	54.94	55.45	54.35	55.46	55.16

Figure 3: Average Hourly Energy Prices in 2030, High Value Case



	Hour																							
Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	42.26	42.65	44.15	45.26	45.88	46.92	44.20	45.59	50.18	36.22	22.99	19.80	20.50	20.27	24.99	35.29	41.22	41.00	40.26	39.33	39.75	40.02	40.79	42.30
2	42.19	42.86	44.01	44.42	44.90	44.32	44.58	43.22	38.69	26.16	-0.17	-7.78	-8.07	-8.56	-8.32	20.98	36.97	37.85	38.49	38.91	38.86	41.08	42.65	42.60
3	37.14	37.94	37.91	37.52	36.71	36.01	34.59	35.18	15.95	0.53	-28.74	-30.00	-30.00	-30.00	-30.00	-17.12	25.71	32.14	33.55	34.93	34.57	35.03	36.99	37.17
4	31.40	30.43	31.19	31.20	29.66	30.89	26.57	19.79	0.58	-24.58	-30.00	-30.00	-30.00	-30.00	-30.00	-30.00	14.60	20.26	29.52	28.67	31.48	33.33	36.46	34.42
5	30.01	30.01	28.27	26.91	26.39	24.63	25.40	10.12	-1.49	-13.75	-14.67	-24.44	-22.88	-16.91	-9.36	-1.57	23.03	23.42	33.48	30.48	30.85	36.80	42.87	34.74
6	39.43	38.03	38.68	38.62	38.63	38.04	34.96	28.01	16.61	-0.11	-8.55	-16.69	-21.32	-22.23	10.58	19.66	28.80	30.46	40.77	42.29	37.66	40.51	45.99	40.80
7	46.48	47.44	47.84	47.89	47.80	48.79	42.31	34.50	20.17	18.27	17.55	9.41	0.28	6.70	28.47	37.61	43.38	53.65	69.86	64.66	54.89	51.13	52.89	47.58
8	52.62	52.21	52.34	51.59	51.12	51.25	48.87	36.59	21.26	19.60	7.74	-5.96	-7.01	2.40	30.41	43.01	44.40	64.91	82.78	75.45	60.48	62.87	62.23	51.45
9	54.22	52.46	49.61	46.70	47.38	48.33	49.81	35.89	20.28	12.84	-2.06	-6.09	-7.51	-3.49	25.09	37.51	48.83	78.91	75.23	63.94	64.11	58.06	57.81	54.96
10	47.01	46.90	45.81	45.12	43.01	44.49	52.31	42.04	13.29	-0.05	-22.96	-25.67	-25.85	-18.75	20.61	37.70	54.40	71.15	79.24	67.13	56.06	52.97	48.31	48.79
11	43.81	43.42	43.25	43.31	43.59	43.80	46.82	46.48	26.54	16.28	-3.50	-13.00	-6.97	-2.71	25.09	38.58	44.28	44.17	43.90	43.09	45.52	47.51	48.79	44.30
12	42.92	43.35	44.12	45.57	45.58	45.32	42.94	45.15	45.34	36.75	28.50	27.39	27.29	30.21	34.07	40.56	45.41	46.20	44.24	43.77	42.25	42.73	44.70	43.41

Generation capacity value is estimated for the base and high value scenarios using a net cost of new entry (Net CONE) calculation assuming a new combustion turbine would be built to meet additional generation peaking capacity needs. The base scenario aligns more with current market conditions where there is not a near term need for additional generation capacity, leading to values of $76/kW-Yr. in 2018 and rising to $121/kW-Yr. in 2030. In the high value scenario, we assume 2018 is the resource balance year, giving values of $124/kW-Yr. in 2018 and rising to $144/kW-Yr. in 2030. Given recent approvals by the CPUC for energy storage projects, it is possible that in the near future a zero emissions resource, such as battery energy storage, may be a more appropriate reference resource with a much greater avoided cost for generation capacity.

Although distribution network capacity can be very valuable, the value is very location specific, and the opportunities to defer distribution upgrades with DERs can be limited. Based on an analysis of distribution avoided costs filed with the CPUC, we chose a distribution capacity value of $20/kW-Yr. in the base scenario and $120/kW-Yr. for the high value scenario, with the high value scenario representing a capacity constrained area in Southern California.

V2G delivers value over V1G

Our modeling shows that V2G technology can transform an EV from a load that the utility incurs a cost to serve into a DER that creates significant benefits. The total cost or benefit and the avoided cost component value streams are shown for several VGI use cases in figures 4 and 5 for the base scenario and high value scenario respectively. The figures show the costs and benefits to the utility from serving and managing a group of 5 EVs in the different use cases on a levelized per vehicle, per year basis. Generation capacity, distribution capacity, and AS are the most significant value streams captured, while the energy benefits are relatively small. When AS is not provided, there is an energy value stream benefit, but when AS is provided, energy costs are incurred to fuel greater participation in AS markets. In the high value scenario, the ability to provide AS offers very little benefit over load shifting with V2G. We also studied a sensitivity case in the high value scenario, where the model's constraints and penalties to reduce battery degradation are removed. In that case, the total benefit rose by $359/veh.-yr. along with the annual energy discharged, from 10,225 kWh/veh.-yr. to 15,051 kWh/veh.-yr..

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The incremental values of V1G and V2G technologies are shown in table 1 for the different scenarios and use cases. The table also includes annual energy discharged per vehicle with V2G.

Figure 4. Levelized Costs and Benefits for Base Scenario Under Utility Control

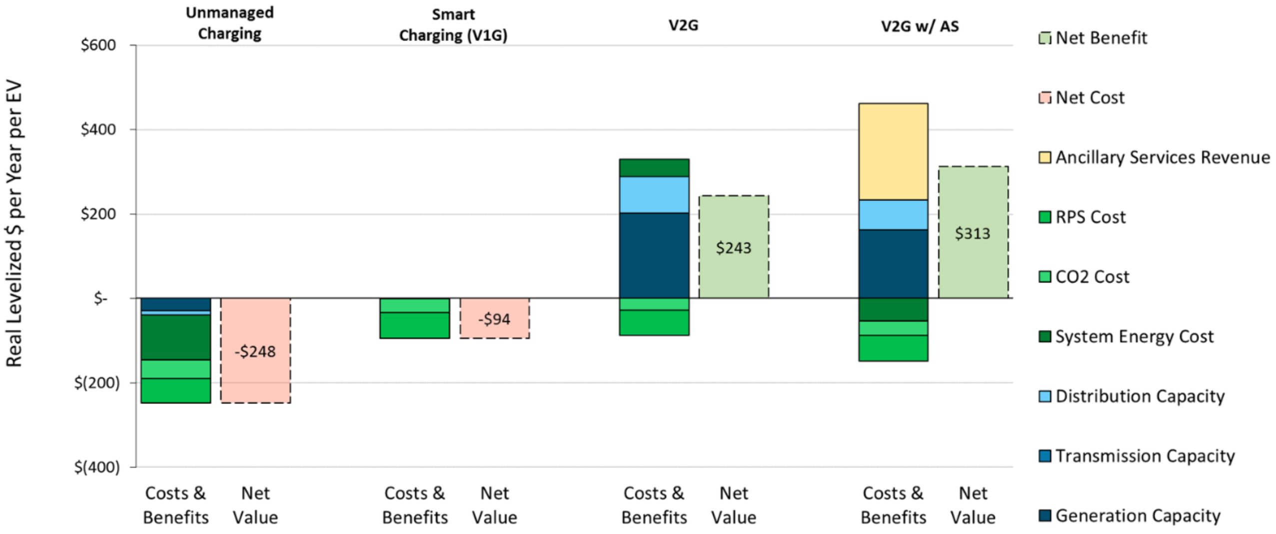

Figure 5. Levelized Costs and Benefits for High Value Scenario Under Utility Control

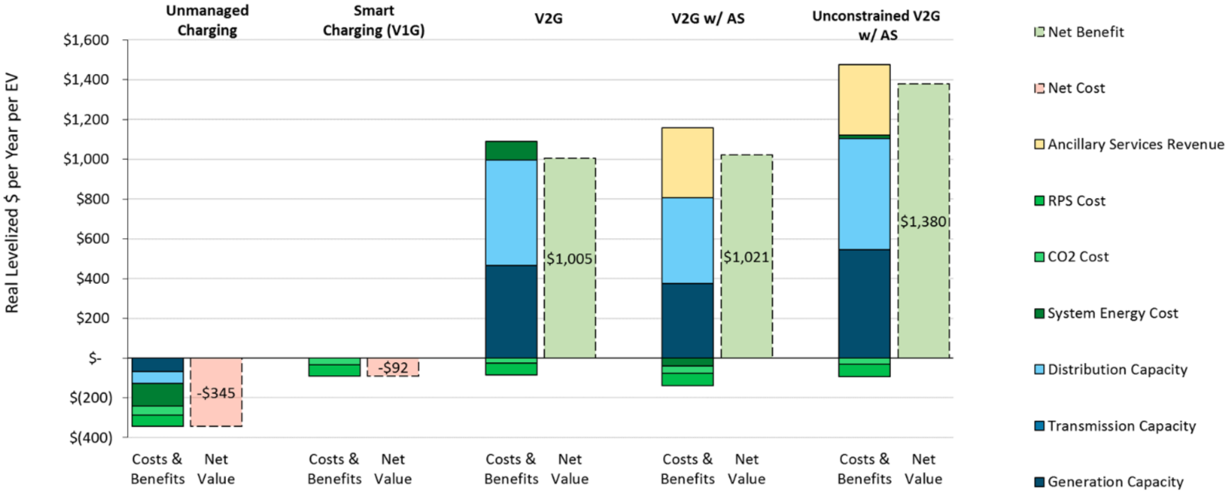

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Table 1. Summary of Incremental Benefits and Discharging for VGI Use Cases (Average per Vehicle)

Scenario	AS Provided with V2G?	V1G vs. Unmanaged	V2G vs. V1G	Energy Discharged (kWh)
Unconstrained High Value	Yes	$253	$1,472	15,051
High Value	Yes	$253	$1,113	10,225
High Value	No	$253	$1,097	7,969
Base	Yes	$154	$407	9,454
Base	No	$154	$337	6,322

Note: Incremental benefits are in terms of utility's costs and benefits of serving and managing EV charging. Incremental costs for equipment and enabling technology are not included in this calculation.

Realizing the value of V2G

The results of our modeling make it clear that it will be most advantageous to deploy V2G technology in generation and distribution capacity constrained locations, where the value of V2G can be more than 4 times that of V1G. If energy storage becomes the preferred generation capacity resource, then all of the values presented in table 1 will be even greater. When automakers design V2G systems as a feature on vehicles, they must be convinced that any additional battery wear and tear will be outweighed by the V2G benefits for the vehicle owner. Our modeling shows that relaxing limits on discharging the battery would increase the electric grid value of V2G by 32%, but the energy discharged would also increase by 47%. Challenges must still be overcome before customers can access the large potential value streams of distribution capacity and AS. There may only be a few locations with significant distribution value and VGI must still be proven as a reliable resource for distribution planning before distribution value can be earned. We also see that the small incremental benefit of providing AS over performing load shifting with V2G may not be worth the cost of the expensive communications and equipment necessary to participate in today's AS markets. When industry is ready to adopt V2G, it will need to develop new business models and vehicle warrantees that share these costs, benefits, and risks of V2G between the automaker, the vehicle owner, the utility, and the VGI service providers.

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