DOCKETED	
Docket Number:	22-EVI-06
Project Title:	Vehicle-Grid Integration
TN #:	268952
Document Title:	A roadmap to unlocking the benefits of bidirectional charging
Description:	This document joins a series of statements the CEC has issued in the past on the topics of driver experience and VGI, including a recent statement on Plug & Charge implementation in California. This document signals CEC's commitment to realizing the benefits of bidirectional EV charging in California. It describes and references ongoing CEC activities and projects that demonstrate substantial potential and progress.
Filer:	Vincent Weyl
Organization:	California Energy Commission
Submitter Role:	Public Agency
Submission Date:	3/5/2026 1:48:06 PM
Docketed Date:	3/5/2026

California ENERGY COMMISSION

A ROADMAP TO UNLOCKING THE BENEFITS OF BIDIRECTIONAL CHARGING

March 2026

Bidirectional charging can turn California's electric vehicles (EV) into flexible energy resources that save drivers money and bring substantial grid benefits, particularly reduced peak demand and improved resilience. This document assesses the opportunity and potential of bidirectional charging and describes analysis by CEC staff and partners that modeled the impacts of vehicle-to-home (V2H) bidirectional charging. It also describes the current implementation status and the California Energy Commission's (CEC) efforts to enable the availability of bidirectional solutions at scale. It further identifies the key remaining barriers and proposes clear next steps the state can take to accelerate the adoption of bidirectional charging and unlock its benefits for Californians.

ABSTRACT

California's transition to zero-emission vehicles (ZEV) creates unprecedented opportunities for grid modernization. While all EVs can charge in a flexible and grid-friendly manner, bidirectional charging transforms EVs into even more flexible energy assets, enabling them to store and export electricity.

Automakers are rapidly deploying bidirectional capability across an increasingly affordable range of EV models. Supporting this movement, the CEC is funding bidirectional charger development, interoperability testing labs, and early deployments of bidirectional EV charging systems.

In 2025, the CEC worked with partners to model the impacts of vehicle-to-home (V2H) bidirectional charging. As of 2025, California's EV fleet represented an estimated ~18.5 GW of potential energy storage capacity, surpassing stationary storage resources statewide. Modeling showed that V2H adoption could reduce peak residential demand by up to 5 GW in 2030. With V2H, drivers can benefit through resilience and bill savings, with projected savings averaging $262–$321 each summer season. V2H benefits the grid by either "removing" the home from the grid for a period of time or reducing the amount of energy that needs to be drawn from the grid.

Key barriers to wide adoption and utilization of EV bidirectional capability remain, including interoperability gaps, upfront costs beyond EV purchase for utilization, complex interconnection requirements, and a lack of direct compensation if bidirectional capability is used for grid export.

Near-term focus on non-export V2H sidesteps some of these barriers while enabling immediate benefits. Coordinated action by CEC, the California Public Utilities Commission (CPUC), and the California Air Resources Board (CARB) should encourage industry to make V2H widely available while stakeholders collaborate to unlock the full benefits of bidirectional charging at scale.

THE CASE FOR BIDIRECTIONAL CHARGING IN CALIFORNIA

California has set ambitious targets for ZEV adoption, including a goal to reach 100% ZEV sales for new light-duty vehicles by 2035[1]. Despite recent changes in federal policy, California remains committed to the adoption of ZEVs and considers them critical to mitigate the effects of climate change.

Enabling bidirectional charging capability can accelerate the transition to EVs by fundamentally expanding the benefits EVs provide to end users. EVs become multi-purpose, no longer just vehicles but also smart e-mobility equipment capable of storing and exporting energy when and where it is needed the most. Such a transformation echoes the remarkably rapid shift from mobile phones to smartphones[2].

The pace and scale of the transition to bidirectional EVs remain to be seen. Still, it has the potential to have impacts on the electric grid comparable to those of solar and stationary storage.

Collectively, EVs represent a massive Distributed Energy Resource (DER) potential

The number of ZEVs on California roads continues to increase steadily, topping 2.1million vehicles[3] at the end of 2025, fueled notably by record sales in the third quarter when over 29% of new cars sold in California were ZEVs.

In parallel, the technical performance of EV batteries has improved, with the average onboard charger power now reaching close to 11 kW for light-duty battery EVs and the average battery capacity exceeding 80 kWh.

Therefore, BEVs collectively represent a massive, distributed storage resource with the potential to grow much larger as EV adoption and battery improvements continue. The chart below describes the evolution of the total storage capacity of California's light-duty BEV fleet over the past 10 years. At the end of 2025, with an estimated 18.5 GW, EV storage capacity already surpasses the total capacity of stationary storage[4]. For comparison, California's historical statewide peak electricity demand was 52 GW in September 2022[5].

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[1] Executive Order N-79-20

[2] Modern smartphones were first introduced in 2007. Just four years later, 35% of Americans owned a smartphone, climbing to 77% in late 2016. Today smartphones have completely eclipsed mobile phones with over 90% ownership (source: Pew Research).

[3] The on-road population of ZEVs is obtained by subtracting vehicles that have been retired or have moved out of state from the total number of ZEVs sold in the state. Early 2026, CEC reported that the total number of ZEVs sold in California surpassed 2.5 million by end of 2025.

[4] https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/california-energy-storage-system-survey

[5] https://www.caiso.com/documents/californiaisopeakloadhistory.pdf

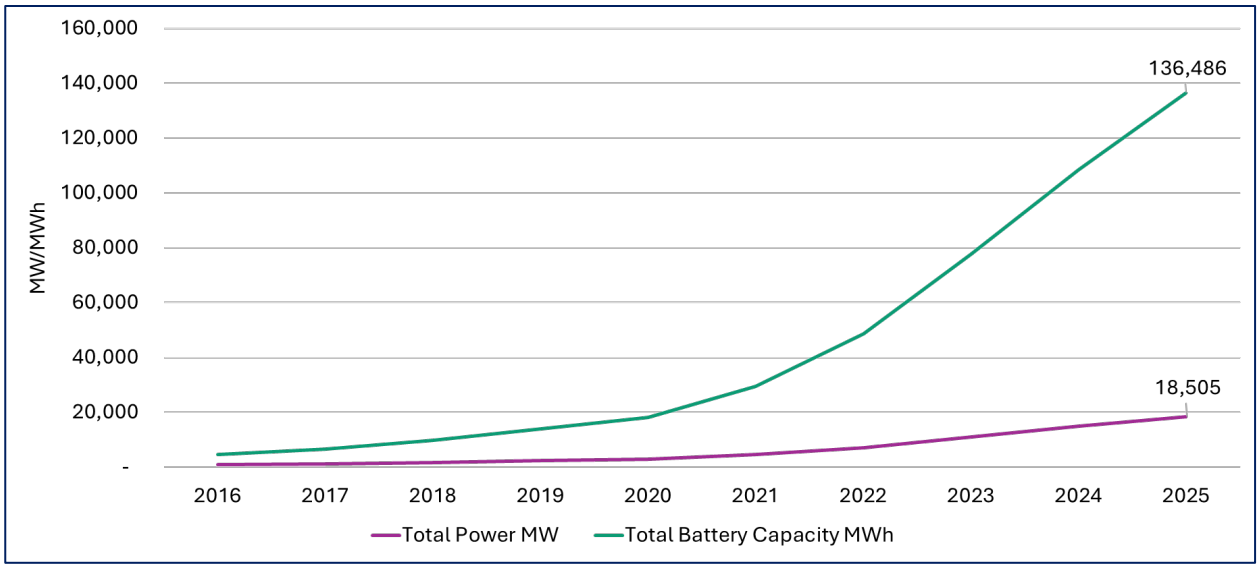

Figure 1: Total capacity of on-road light-duty BEV batteries in California (Source: CEC)

Personal light-duty vehicles are typically used for driving only about 5% of the time[6], meaning bidirectional-capable EVs would be available for a large majority of the time to provide valuable energy services to vehicle operators and the electric grid.

Bidirectional charging offers significant benefits

There is an extensive body of work, developed over a decade by the private sector and academic experts, that inventories bidirectional charging use cases and evaluates benefits across different scenarios. This document is not intended to revisit nor specifically reference such studies. The CEC uses its own methods and tools to forecast the availability of bidirectional charging and estimate its impact.

Bidirectional charging will become the largest potential source of demand flexibility in California

Among its contributions of demand scenarios to the SB 100 Joint Agency Report, joint agency staff modeled and estimated demand flexibility from various sources during peak hours[7]. The results presented in the chart below show that by a wide margin, EVs represent the largest contributor to load flexibility (multiple gigawatts) and that bidirectional charging ("EV V2X") provides approximately three times the value of unidirectional charging ("EV Charging").

[6] Source: U.S. Department of Transportation, Federal Highway Administration, Summary of Travel Trends: 2022 National Household Travel Survey, January 2024

[7] https://efiling.energy.ca.gov/GetDocument.aspx?tn=258363&DocumentContentId=94382

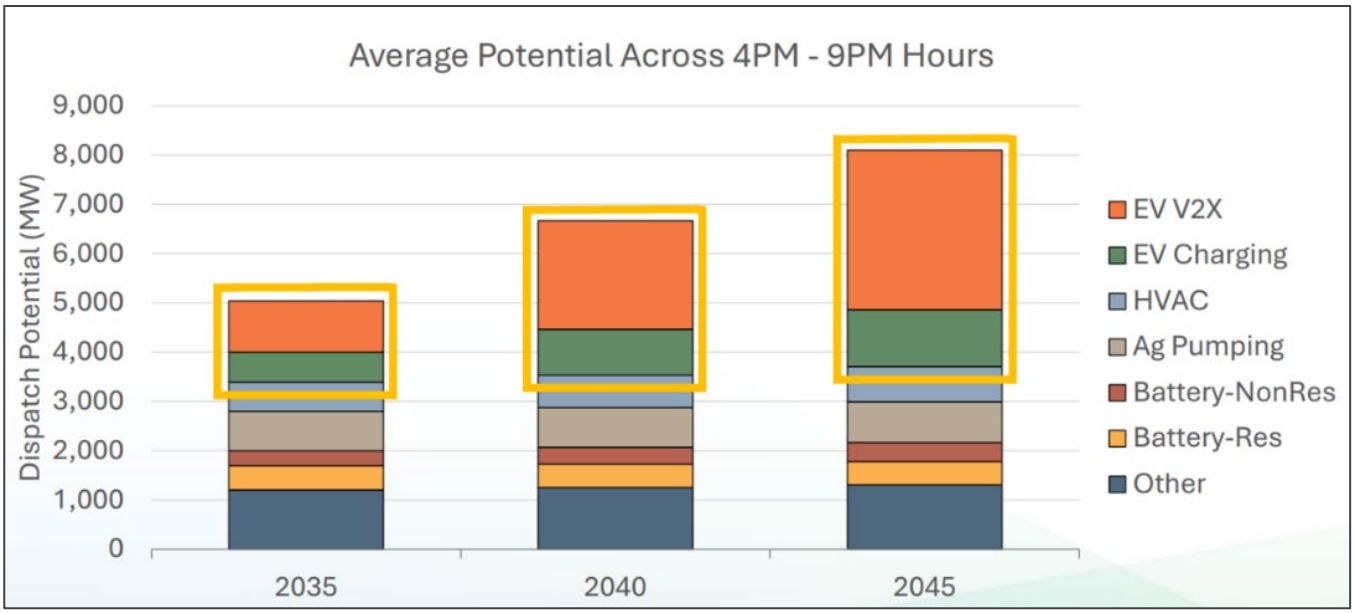

Figure 2: Demand flexibility potential of different resources

Near term Vehicle-to-Home adoption would reduce peak residential load and stress on the grid

In 2025, as part of its ongoing work on the EV Charging Infrastructure Assessment Report pursuant to AB 2127, the CEC collaborated with the National Laboratory of the Rockies (NLR) to estimate the potential benefits to vehicle owners and to the grid of bidirectional charging at scale. Specifically, staff looked at light-duty vehicles with access to home charging at single-family homes discharging during peak hours, without requiring any changes to driving behavior or home electricity usage, nor any intervention from drivers other than plugging in the vehicle when they get home. The analysis considered both off-grid scenarios (the home is physically disconnected from the grid when discharging) and grid-parallel scenarios (the vehicle is physically connected to the grid through the home electrical infrastructure, but the discharge power is limited to be less than or equal to the power the home is consuming – termed the "non-export V2H" scenario). The rationale for examining the off-grid scenario is to allow customers to avoid the interconnection process with their utility. Further details and an update of the analysis will be available in the third AB 2127 charging infrastructure assessment[8], to be published in 2026.

The results in the table below demonstrate a compelling beneficial impact at both home and grid levels, from several hundred dollars saved on average by EV drivers in just the four summer months, to up to 5 GW of load removed from the grid during peak hours, representing a significant percentage of the state's total residential load. Systems that are connected and operate in parallel with the grid provide slightly increased benefits but are more complex to implement in the near term.

[8] When published, the third assessment will be available from this web page: https://www.energy.ca.gov/data-reports/reports/electric-vehicle-charging-infrastructure-assessment-ab-2127.

Vehicle-to-Home Potential in 2030 *(based on 4.5M EVs in 2030)*	Off grid (grid disconnected)	Grid-parallel (grid connected)
EVs available to discharge at least once per week	2.3M 51.7% of EVs	2.36M 53% of EVs
Average potential bill savings per EV (June to September)	$262	$321
Percentage of residential load served during peak	9.4%	11.6%
Max grid load reduction (during peak hours)	4.1 GW	5 GW

Figure 3: Key results of Vehicle-to-Home potential analysis

BIDIRECTIONAL CHARGING IS READY TO TAKE OFF

The potential of bidirectional charging is increasingly recognized by end users, automakers, the energy services industry, and policy agencies, all signaling readiness to implement and scale the capability immediately.

End users are ready to embrace bidirectional charging

Managed charging programs across the U.S., including in California, have demonstrated EV drivers' willingness to adjust their charging behavior and even relinquish control of their charging equipment if it results in meaningful benefits, such as reduction of their electric bill. In a recent survey, Plug In America found that a large majority of EV drivers are willing to enroll in a bidirectional charging program, and over half of them would be willing to pay more for an EV that has bidirectional charging capabilities.

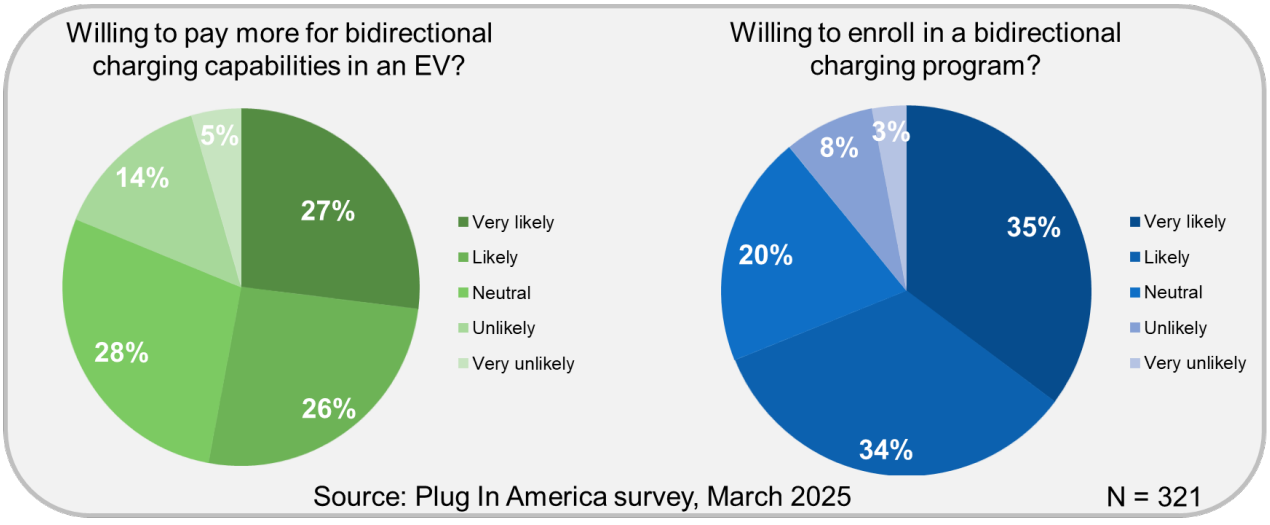

Figure 4: EV Driver willingness to adopt bidirectional charging (data from Plug In America)

EV manufacturers are making bidirectional capability more accessible

Bidirectional-capable EVs have been around for years: the 2013 Nissan Leaf was the first fully bidirectional-capable EV launched in the U.S. Today, several prominent EV manufacturers have commercially available vehicles capable of bidirectional charging in their lineups, such as the Kia EV9,

the Lucid Air, the Ford F-150 and the Tesla Cybertruck. What started generally as a rather exclusive option implemented in high-end models is becoming mainstream. GM stated that almost their entire electric vehicle line-up is now bidirectional-capable, and that in 2026 it will include a recently announced Chevy Bolt, which will sell at a starting price below $30k. Rivian, Kia, Hyundai, Volvo, and Polestar[9] have all announced bidirectional-capable vehicles priced at the same level or lower than their current EV models.

On the equipment side, GM has announced a leasing option[10] for bidirectional equipment to mitigate the high upfront cost of the infrastructure and installation required to operate bidirectional charging at home. Ford has launched Ford Home Power[11], adding energy-pricing arbitrage to the backup use case, further improving the return on investment of their V2H solution.

EV manufacturers are moving rapidly and decisively to make bidirectional charging a real possibility for American drivers.

CEC is already implementing programs that support scaled-up deployments

The CEC is committed to a successful transition to bidirectional charging and seamless vehicle-grid integration (VGI). It is not the sole state agency with a leading role to play. It collaborates with other state agencies, including the Air Resources Board (CARB) and the Public Utilities Commission (CPUC) to design and implement policies that help the state meet this objective.

The CEC is the lead agency for building California's EV charging infrastructure, including the development and deployment of bidirectional-capable equipment. The CEC has been an early proponent of VGI and bidirectional charging and has taken multiple key steps to enable its progress as illustrated below.

[9] https://www.cnet.com/home/electric-vehicles/bidirectional-charging-and-evs-how-does-it-work-and-which-cars-have-it/

[10] https://gmauthority.com/blog/2025/10/gm-energy-to-begin-leasing-bidirectional-ev-charging-system-in-2026/

[11] https://fordauthority.com/2025/10/ford-power-home-management-allows-f-150-lightning-owners-to-power-their-homes-every-day/

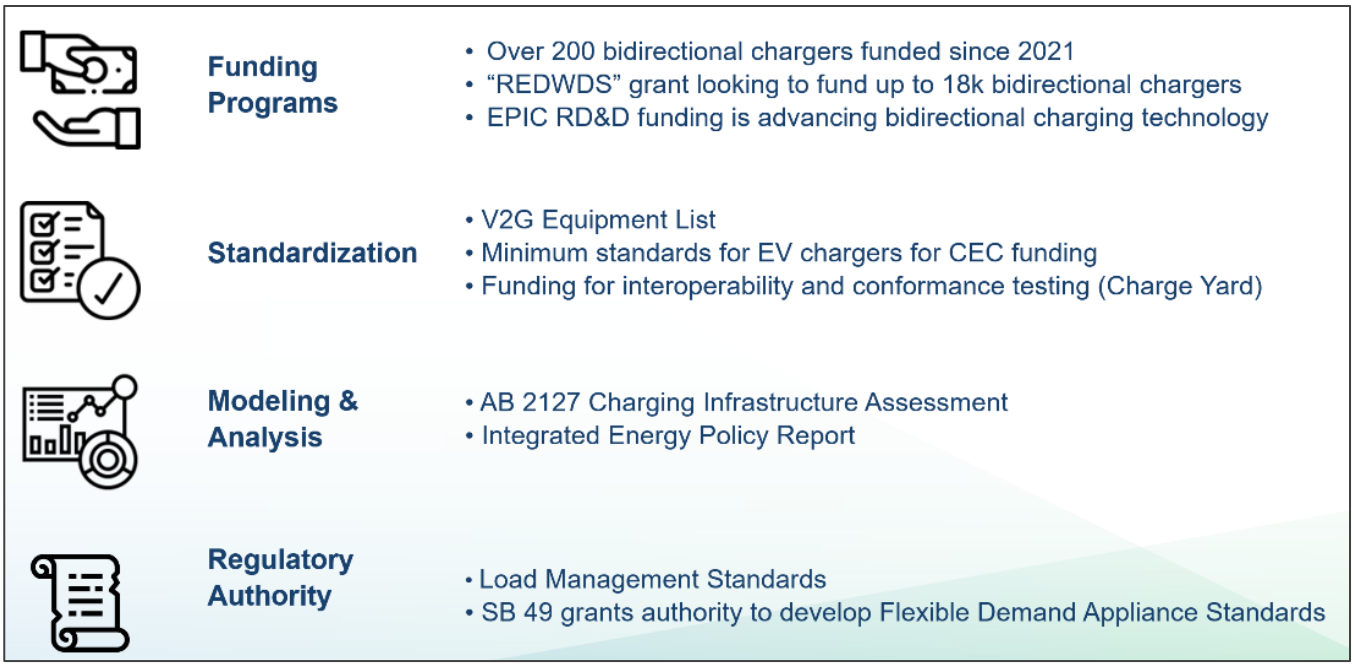

Figure 5: Categories of CEC actions supporting bidirectional charging

At full funding and if all projects were successfully executed, the "REDWDS[12]" grant program would fund more than 18,000 bidirectional charger deployments, primarily in the residential sector and with some on California farms. The CEC maintains a list[13] of vehicle-to-grid (V2G) equipment, comprised of bidirectional chargers meeting required safety standards. The CEC funded a soon-to-be-operational interoperability testing lab (Charge Yard[14]) designed to accelerate a future where any vehicle can charge or discharge at any charger, regardless of the vehicle manufacturer, which network operates the charger, or which distribution grid it is connected to.

In addition to these critical field activities aimed at making bidirectional charging a practical reality, the CEC also conducts many analyses and forecasting activities to inform future policy, and in these efforts continues to factor in increased contributions of bidirectional charging as illustrated in the previous section.

[12] https://www.energy.ca.gov/solicitations/2023-03/gfo-22-609-responsive-easy-charging-products-dynamic-signals-redwds

[13] https://www.energy.ca.gov/programs-and-topics/programs/vehicle-grid-integration-program/vehicle-grid-equipment-list

[14] https://www.energy.ca.gov/solicitations/2025-03/gfo-24-609-charging-interoperability-and-collaboration-yard-charge-yard

BARRIERS TO BROAD ADOPTION REMAIN

Operationalizing bidirectional charging requires a complex system approach that goes beyond the simple integration of an electric vehicle with a charger. It requires technical and business alignment between multiple entities, including the vehicle and driver, the charging equipment, and the electrical infrastructure at the levels of both the home or facility and the grid. This complexity generates multiple challenges and barriers that impact the pace and cost of implementing bidirectional charging.

Limited interoperability and maturing standards

Most bidirectional charging solutions that are commercially available today are bundled offers that include the vehicle, charger, and electrical equipment that interfaces the charger with building electrical infrastructure. The advantages of this type of vertically integrated solution include a reduced number of configurations to test or support, and a faster time-to-market by removing dependencies on certain communication and interoperability standards that are still evolving. However, in most "bundled" cases, the vehicle's bidirectional capabilities do not work with third-party equipment, eliminating product choice and locking in the customer with a single equipment provider. Without interoperability, customers would not be able to keep using their bidirectional charger when they change vehicles, or update their equipment to take advantage of new capabilities or programs if the equipment is not compatible with their vehicle. Interoperability is critical to delivering a seamless end user experience and achieving economies of scale for bidirectional-capable equipment and services. This barrier will be progressively removed as interoperability continues to gain traction among public and private stakeholders. The CEC actively contributes to development of key standards, supervises the deployment of an interoperable charging infrastructure, and facilitates broad interoperability testing in California.

High upfront cost of bidirectional equipment and installation

End users who are willing and ready to deploy bidirectional charging often face steep upfront costs. Not only is their choice of bidirectional capable vehicles limited, but they also need to purchase and deploy multiple pieces of equipment to comply with current electrical requirements and technology limitations. Such equipment may include a bespoke bidirectional charger, a smart inverter, an automated transfer switch, and/or a microgrid interconnect device. Installation costs and permitting fees add to the total upfront cost, in many cases pushing it past $10,000. These costs are expected to continue to decrease over time. That said, this present-day cost – which is still well below the average cost of a solar installation – could become more palatable if the bidirectional charging systems worked with any vehicle and/or supported multiple beneficial use cases beyond home backup during power outages.

Limited ability to interconnect with the electric grid

A bidirectional-capable vehicle connected to an installation that enables discharging is considered a generating facility. If a generating facility is connected to the electric grid through the electrical infrastructure, it can pose safety and stability risks to the grid. To mitigate this, utilities require generating facilities to abide by Rule 21 which sets constraints and operational requirements on any generating facility interconnected with the grid. These constraints include power safety functions and communication requirements generally applicable to smart inverters, as well as a process to request and obtain utility permission to operate the system. Rule 21 in its current state is not adapted to support mobile generation facilities: the vehicle is not always connected, nor is it necessarily connected at the same location. The bidirectional architecture (AC or DC export) also impacts the interconnection topology and requirements. Under the CPUC's leadership, these issues are being investigated with industry stakeholders and utilities. The CEC anticipates that it will take several years to define clear interconnection rules and to develop and roll out a streamlined, cost-effective interconnection process.

Interconnection requirements do not apply to bidirectional EVs utilized in "non-export, grid-disconnected V2H" scenario presented in this whitepaper and thus would not face the same barriers as grid-connected bidirectional EVs.[15]

Limited compensation mechanisms for grid-connected bidirectional charging

Grid-connected bidirectional vehicles can offer many services beyond backup during outages or non-export self-consumption. Just like other loads or distributed energy resources, bidirectional vehicles can respond to emergency signals (e.g. CAISO's Energy Emergency Alert) or participate in demand response programs. They could also export energy to the grid or help with frequency and voltage regulation.

However, beyond pilot initiatives and certain limited programs (e.g., Demand Side Grid Support Program), there is no general compensation mechanism for bidirectional EV charging (e.g., a rate that pays for exported electricity from a bidirectional EV, similar to the Net Billing Tariff or Net Energy Metering).

For many Californians, this is contingent on the investor-owned utilities (IOUs) submitting a proposal to the CPUC through the general rate case (GRC) process. This process is already complex for standard rates. The CPUC processes a GRC for each IOU every four years, and approval takes about two additional years following extensive stakeholder engagement. Export rates have become a point of tense discussion among utilities, the CPUC, and stakeholders, and have not yet comprehensively addressed bidirectional charging. CEC staff anticipate it will take multiple years to establish and roll out a stable compensation mechanism for V2G services. A non-export bidirectional EV rate might become available sooner as an intermediary step.

ENABLING VEHICLE-TO-HOME COULD MAKE BIDIRECTIONAL CHARGING A REALITY TODAY

The CEC is committed to a future where transportation electrification and grid modernization support each other through VGI. Bidirectional charging can provide significant benefits to EV drivers and the electric grid. The CEC recognizes that achieving the full potential of bidirectional charging and VGI means overcoming all the obstacles listed in the barrier section of this document. Recent work shows that V2H could yield significant benefits today while sidestepping the main barriers facing VGI.

While standard organizations, industry stakeholders, and policymakers are actively working to remove VGI barriers under the watchful eyes of eager EV drivers, the outstanding issues will not all be resolved at the same pace. The CEC has deployed significant efforts to advance bidirectional charging and facilitate technological and socio-economic progress through careful funding and other policy activities. More needs to be done. However, if the vehicle is not connected to the grid while powering the home, interconnection is not required, nor is any specific V2G compensation mechanism. Current time-of-use rates are enough to influence drivers' behavior, providing benefits to the grid, ratepayers, and the driver alike. The remaining issue is the availability and affordability of capable vehicles and electrical equipment. Automakers and equipment manufacturers are actively working to address this: more and

[15] Non-export, grid-disconnected vehicle-to-home systems still require a transfer equipment to ensure there is no inadvertent backfeed to the utility line, unless they are permanently isolated.

cheaper EVs support bidirectional capabilities, and innovations such as meter socket adapters and smart panels make their integration more cost-effective.

As this white paper describes, accelerating the adoption of bidirectional capable EVs could provide the state with far expanded flexible energy assets that could reap significant grid reliability and ratepayer benefits. The CEC will continue its work with all stakeholders to accelerate these benefits. Notably, the CEC will continue its collaboration with CARB and the CPUC to support a policy framework for enabling and scaling bidirectional VGI in the state.

In the months to come, the CEC will collaborate with the recipient of the Charge Yard solicitation to build a state-of-the-art testing facility in Sacramento that will help improve interoperability of bidirectional-capable EVs and equipment. Interoperability is critical to achieving scale and cost reduction of end-to-end bidirectional solutions, including VGI.

The CEC will continue to monitor deployments of REDWDS EV charging projects that respond to dynamic grid signals, including bidirectional charging projects, and demonstrate that this approach can scale and lead to grid benefits and end-user savings.

Finally, the CEC will continue to explore ways to overcome the barriers described in this whitepaper, including facilitating and reducing the cost of installation and permitting of EV charging systems that support non-export, grid-disconnected operation.

Please submit any comments regarding this white paper to:

https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=22-EVI-06

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