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Electric Vehicle Charge Management Strategies to Benefit the California Electricity Grid

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Electric Vehicle Charge Management Strategies to Benefit the California Electricity Grid

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California Resilient and Innovative Mobility Initiative

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16. Abstract Recent studies suggest that there could be significant value to electric vehicle (EV) drivers and power companies from incorporating EVs into the state's electrical power grids, known as Vehicle-Grid Integration (VGI). However, the benefits could be highly variable depending on the location of the utility territory, vehicle type and battery capacity, the relevant timeframe, and whether the connection involves only managed charging or includes bidirectional charging permitting vehicle to grid (V2G) power transfer, and other factors. Various studies conducted to date generally conclude that the opportunities for V2G could have two to three times the value of managed (or "smart") charging. However, there are considerable additional complications for grid integration, including variable and site-specific implementation costs. Some savings such as deferring distribution system upgrades can be very significant but are also site-specific and depend on the level of current and projected demands for electric power on the individual distribution feeder lines, and are therefore difficult to predict.		

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List of Abbreviations

AC	Alternating Current
API	Application Programming Interface
BEV	Battery Electric Vehicle
CAISO	California Independent System Operator
CalFUSE	California Flexible Unified Signal for Energy
CCA	Community Choice Aggregation
CCS	Combined Charging System
CEC	California Energy Commission
CPO	Charge Point Operator
CPUC	California Public Utilities Commission
DC	Direct Current
DER	Distributed Energy Resource
DR	Demand Response
DSO	Distribution System Operator
EPRI	Electric Power Research Institute
ESDER	Energy Storage and Distributed Energy Resources
EV	Electric Vehicle
EVSE	Electric Vehicle Service Equipment
FERC	Federal Energy Regulatory Commission
IEEE	Institute of Electrical and Electronics Engineering
IOU	Investor-owned Utilities
ISO	Independent System Operator
LIN-CP	Local Internet Network on the Control Pilot
LSE	Load-Serving Entity

MCS	Megawatt Charging System
MIDAS	Market Informed Demand Automatic Server
MOU	Municipally Owned Utility
NACS	North American Charging Standard
NEVI	National Electric Vehicle Infrastructure
OCA	Open Charge Alliance
OCPP	Open Charge Point Protocol
OpenADR	Open Automated Demand Response
OSCP	Open Smart Charging Protocol
OVGIP	Open Vehicle Grid Integration Platform
PG&E	Pacific Gas and Electric
PKI	Public Key Infrastructure
RTO	Regional Transmission Operator
SAE	Society of Automotive Engineers
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SGIP	Self Generation Incentive Program
SLAC	Signal Level Attenuation Characterization
TLS	Transport Layer Security
TOU	Time-of-Use
VGI	Vehicle Grid Integration
V2G	Vehicle to Grid
V2H	Vehicle to Home
WPT	Wireless Power Transfer

Executive Summary

Executive Summary

Electric vehicles (EVs) are proliferating in California's vehicle fleet, with several dozen models available across market segments. California's nearly two million EVs on the roads leads the country with almost 40 percent of total sales, but with plans for millions more over the next 10 years to meet the state's clean air and climate change mitigation goals.

This growing demand for vehicle charging at all times of the day represents a challenge, but also an opportunity, for electrical grids. On one hand, EV charging can strain local electrical distribution grids, especially when many vehicles are being charged at the same time such as early in the evening. On the other hand, scheduling EV charging has become more flexible, especially with the modern larger capacity batteries, which don't need to be charged as often.

There are many potential advantages to maintaining a connection between EVs and the electrical grid system even when a vehicle is not being charged. This enables a concept known as vehicle-grid integration (VGI), which encompasses the following:

- Charge management or "smart charging" where EVs can charge at opportune times when electricity rates are lower, or which serve to lower greenhouse gas (GHG) grid emissions.
- Bidirectional or "vehicle-to-grid" (V2G) power transfer where batteries onboard vehicles can discharge power to local loads such as houses or offices or to the grid more generally in response to higher power demands, and
- Other types of grid support provided by EVs such as helping to maintain grid voltages and frequencies.

One of the most complicated aspects of VGI is how the very significant values that it offers for utility grids and ratepayers can, at least in part, flow back to the EV drivers who participate in VGI programs.

The basic VGI concept of charge management (not including bidirectional power flow) can take several different forms along with other "demand response" types of grid resources. Demand response (DR) programs let users shift their energy use in particular ways in response to price or other signals from the utility. These different types of responses have come to be known as "shed, shift, shape, and shimmy" that refer to reducing grid peaks, shifting electricity use over various time periods, adjusting local customer demand levels in response to time-of-use utility rates, and short-term adjustments in power demands to reduce local loads and maintain grid frequency. EVs can perform all of these services with various implications for grid operations and customer utility bills.

V2G or bidirectional power is a VGI concept in which the grid can draw power directly from EVs. This concept has been understood for over 25 years but only in recent years have commercially available vehicles had this capability. Essentially, bidirectional EVs can act as mobile batteries that can be charged and discharged at opportune times and locations to significantly extend the value to the grid beyond managed charging.

The State of California has been actively pursuing research and demonstration projects around these VGI concepts for many years. This includes producing a "Vehicle-Grid Integration Roadmap" in 2014 with leadership from the California Independent System Operator (CAISO), a nonprofit public benefit corporation that manages energy flow over much of the state's energy grid, and participation by various state agencies and industry stakeholders. The document provided a typology of VGI services, described state efforts at that time to promote various concepts around smart charging and grid integration, and discussed the status of various communication standards (CAISO, 2014).

While still in some degree of flux, with 2023 seeing both cross-automaker adoption of the North American Charging System (NACS) connector and ratification of LIN-CP (local internet network on the control pilot) in SAE J3068 for high-function alternating current (AC) VGI communications, the physical plug and communication standards for VGI are coming into better focus. There are now multiple end-to-end solutions for sending communication signals from utility grid operators, local commercial and residential sites, and load aggregators through to EV owners in ways that allow them to participate in load shifting programs for their economic benefit. Load aggregators bundle multiple households and/or other (commercial, university, municipal, etc.) sites together so that large blocks of power can be bid into power markets that all have minimum size requirements.

Many studies have shown that integrating EVs with electric utility grids has multiple potential advantages. Various VGI applications can in some cases be combined for greater benefit of EV owners and ultimately for all ratepayers, but of course with greater complexity than single applications.

Recent studies suggest that the value to EV drivers from VGI services are highly variable based on their location, vehicle type and battery capacity, smart charging versus V2G capability, present or future timeframe, and other factors. A general conclusion that can be drawn from the various studies conducted to date is that the opportunities for V2G could have two to three times the value of managed or "smart" charging. These simpler concepts involve changing the timing and potentially the location of charging (e.g., home vs. work), without any notion of bidirectional power flow.

V2G implementation raises considerable additional complications for grid integration, because of power backfeeding and market access rules, and with variable and site-specific implementation costs. Some advantages such as providing backup power and deferring upgrades to the power distribution system can be very significant but are also site-specific. For example, the value of deferring grid upgrades depends on the level of current and projected congestion on individual distribution feeder lines and is therefore difficult to predict. Wholesale markets are uniform across regional transmission system operators and can be highly lucrative but are still subject to legacy market entry barriers.

Based on the current technical and economic status of VGI in California, we recommend the following.

Recommendation 1: Encourage Automotive Companies to Include V2G Capability in Their EV Models

The state should consider offering auto companies program credits and incentives to include V2G capability in their EVs. V2G requires both a bidirectional charger and some VGI signaling such as LIN-

CP as defined in SAE J3068. This capability can allow vehicles to provide grid services beyond what is allowed by basic smart/flexible charging as well as emergency backup power for homes, businesses, and community emergency shelters. The state should consider incentives to help EV drivers with medically necessary devices to use their EVs for emergency backup power, as well as helping to enable V2G for other emergency power needs. The state should consider incentives for EVs that are used for such bidirectional services.

Recommendation 2: Include EV-Based V2G in the California Self-Generation Incentive Program (SGIP)

The California SGIP currently supports stationary batteries for grid support and local power reliability. EVs with V2G capability can function like stationary batteries at much lower cost and should be considered allowable resources with appropriate incentive levels set by state regulators.

Recommendation 3: Allow EV Owning Households to Participate in More than One Utility Demand Response (DR) Program

Some EV owning households in California have found difficulty in participating in utility sponsored Demand Response (DR) programs for EVs, which can reduce electricity bills by shifting vehicle charging to other times of day, if they happen to also have enrolled in a separate similar program related, for example, to their household thermostat or electric water heater. Households should be able to participate in one or more DR programs that all contribute to reducing loads on the grid during key times.

Recommendation 4: Support the Use of Onboard EV Inverters for Grid Interconnection

The state should support broader efforts to enable onboard inverters to be certified for grid interconnections using the AC interfaces on the vehicles, obviating the need for duplicate inverter systems. EVs can charge using either AC or direct current (DC) charging ports but cannot (yet) discharge using AC because of this inverter certification issue. This means use of emerging standards such as UL 1741-SC and SAE J3072, which implement safe AC interconnection of onboard inverters.

Recommendation 5: Establish State VGI Targets for 2030 and Beyond

Similar to state procurement targets for battery-based storage in each utility service territory, California could require investor-owned utilities (IOUs) and encourage municipally owned utilities (MOUs) to similarly participate in programs to establish the minimum number of bidirectional chargers and enrolled vehicles needed to provide important grid support for the ultimate benefit of electricity ratepayers.

Contents

Introduction

Electric vehicles (EVs) are making strong inroads into California's vehicle inventory with over 1.8 million plug-in vehicles sold as of early 2024. These vehicles are of two primary types: 1) fully battery-powered vehicles (BEVs), and 2) plug-in hybrid vehicles (PHEVs) with dual fuel (gasoline and electricity) capability. Modern BEVs have much larger battery packs than they did several years ago, typically now on the order of 60-80 kilowatt hours (kWh) that provide 200-300 mile driving ranges. These improved BEVs are more useful to drivers by allowing them to take long-range trips, aided by a growing network of fast chargers. With greater energy storage capacity, they also provide expanded opportunities for vehicles to act as electricity grid resources for the state.

This concept is known as "vehicle-grid integration" (VGI), where EVs can be "good citizens" for the grid by providing various types of support, versus simply acting as additional electrical loads. As these concepts evolve and become more widely implemented, EV drivers can benefit from payments they receive for reducing household and/or workplace loads at critical times, and potentially having more reliable power. As described by the California Energy Commission (CEC):

> Vehicle-grid integration (VGI) refers to technologies, policies, and strategies for electric vehicle (EV) charging which alter the time, power level, or location of the charging (or discharging) in a manner that benefits the grid while still meeting drivers' mobility needs. Examples of VGI include managed charging (also known as V1G or smart charging) and bidirectional charging (including vehicle-to-home [V2H] and vehicle-to-grid [V2G]). VGI is a key tool for achieving California's decarbonization and electric vehicle adoption goals.[1]

The basic concept of charge management (not including bidirectional power flow) can take several different forms along with other "demand response" types of grid resources. Demand response (DR} programs let users shift their energy use in particular ways in response to price or other signals from the utility. These different types of responses have come to be known as "shed, shift, shape, and shimmy" that refer to reducing grid peaks, shifting electricity use over various time periods, adjusting local customer demand levels in response to time-of-use utility rates, and short-term adjustments in power demands to reduce local loads and maintain grid frequency. These are discussed in more detail later in this report. EVs can perform all these services with various implications for grid operations and customer utility bills.

The state of California has been actively pursuing research and demonstration projects around these VGI concepts for many years. This includes producing a "Vehicle-Grid Integration Roadmap" in 2014 with leadership from the California Independent System Operator (CAISO), a nonprofit public benefit corporation that manages energy flow over much of the state's energy grid, and participation by various state agencies and industry stakeholders. This document provided a

[1] https://www.energy.ca.gov/programs-and-topics/programs/vehicle-grid-integration-program#:~:text=Vehicle%2Dgrid%20integration%20(VGI),still%20meeting%20drivers'%20mobility%20needs

typology of VGI services, described state efforts at that time to promote various concepts around smart charging and grid integration, and discussed the status of various communication standards (CAISO, 2014).

To facilitate the interactions of EVs and the grid, there is an emerging suite of communications standards to send appropriate grid signals to which vehicles may respond. There are two primary pathways for controlling EV charging to benefit the operation of the electrical grid: 1) control through the vehicle charger (also known as electric vehicle service equipment or EVSE), requiring a "smart" charger with communications capability, and 2) control through the vehicle itself through the telematics systems that are included in all modern vehicles. The advantage of the first option is that at sites with smart chargers, charging can be controlled for any EV that connects with that charger. The advantage of the second option is that charging can be controlled regardless of what type of charger is connected to the EV, even basic chargers with no built-in communications capability. Figure 1 below presents some of the major communication pathways and protocols that have been developed in recent years.

Source: California Energy Commission

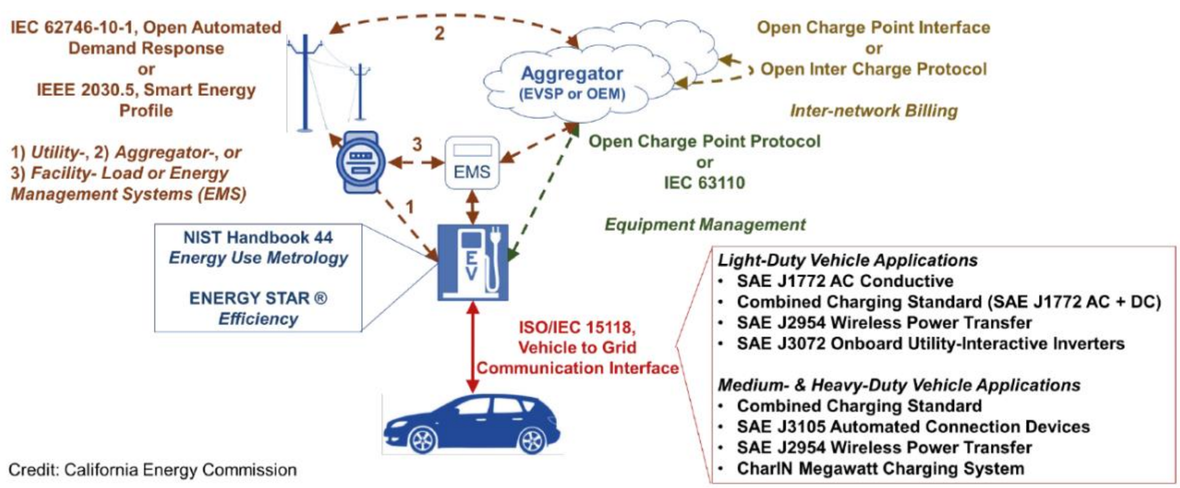

Figure 1. Vehicle-Grid Integration Communication Protocols

A more advanced VGI concept is vehicle-to-grid (V2G) or bidirectional charging. This capability can allow vehicles to provide grid services beyond those provided by basic smart/flexible charging by supplying grid support and/or emergency backup power for homes, businesses, and community shelters. This concept has been understood for over 25 years but only in recent years have commercially available vehicles had this capability. General Motors and Tesla have announced that they will include V2G capability in all models sold in the U.S. by 2025/2026.

This report summarizes recent research results from real-world VGI programs and their identified benefits, describes progress in California on moving to more dynamic (hourly changing) electricity prices, summarizes grid management strategies and state agency efforts to support VGI, and makes policy recommendations. Additional appendices summarize relevant and recent state legislation and describe the key technical concepts and communication protocols needed to control EV charging for achieving grid benefits.

Benefits of Vehicle-Grid Integration

EVs and electric utility grids can interact in complex ways for the potential benefit of grid operations. This can lower costs that can ultimately translate into lower electricity prices for ratepayers. When demand for electricity is high utilities must generate more power by, for instance, bringing more generators online in addition to tapping into renewable resources such as solar or wind. Conversely, when demand is low utilities must shut down some generators or find other loads that can absorb the excess power being generated. Either of these actions can be expensive and increase electric costs.

Power use is typically highest in the late afternoon and early evening, which is why utilities often asked customers to use heavy appliances like clothes dryers at other times, and where we now have time-of-use (TOU) rates that are highest from 4-9PM to encourage off-peak power use. Today utilities are more and more drawing on renewable sources, like solar, that operate during daylight hours, which requires them to cut back on other resources like fossil fuels. Planners are expecting the growth of EVs to increasingly stress the grid from drivers charging their vehicles in the evening and night hours when renewable electricity production is typically less. This is prompting calls to shift EV charging to the daytime, when drivers are often working, and their vehicles are parked and not in use.

Balancing electrical power supply and demand is critically important to maintaining system voltages and frequencies within acceptable ranges. Ideally, utilities would prefer that electricity demand remain more or less consistent throughout the day and in step with electricity production. DR systems can address these problems by increasing or reducing energy demands or shifting them to other time periods, and thus lower electricity prices. Managed EV charging can provide all of the classic DR type services that have been termed “shed, shift, shape, and shimmy.” Figure 2 below depicts these concepts, which are briefly described below.

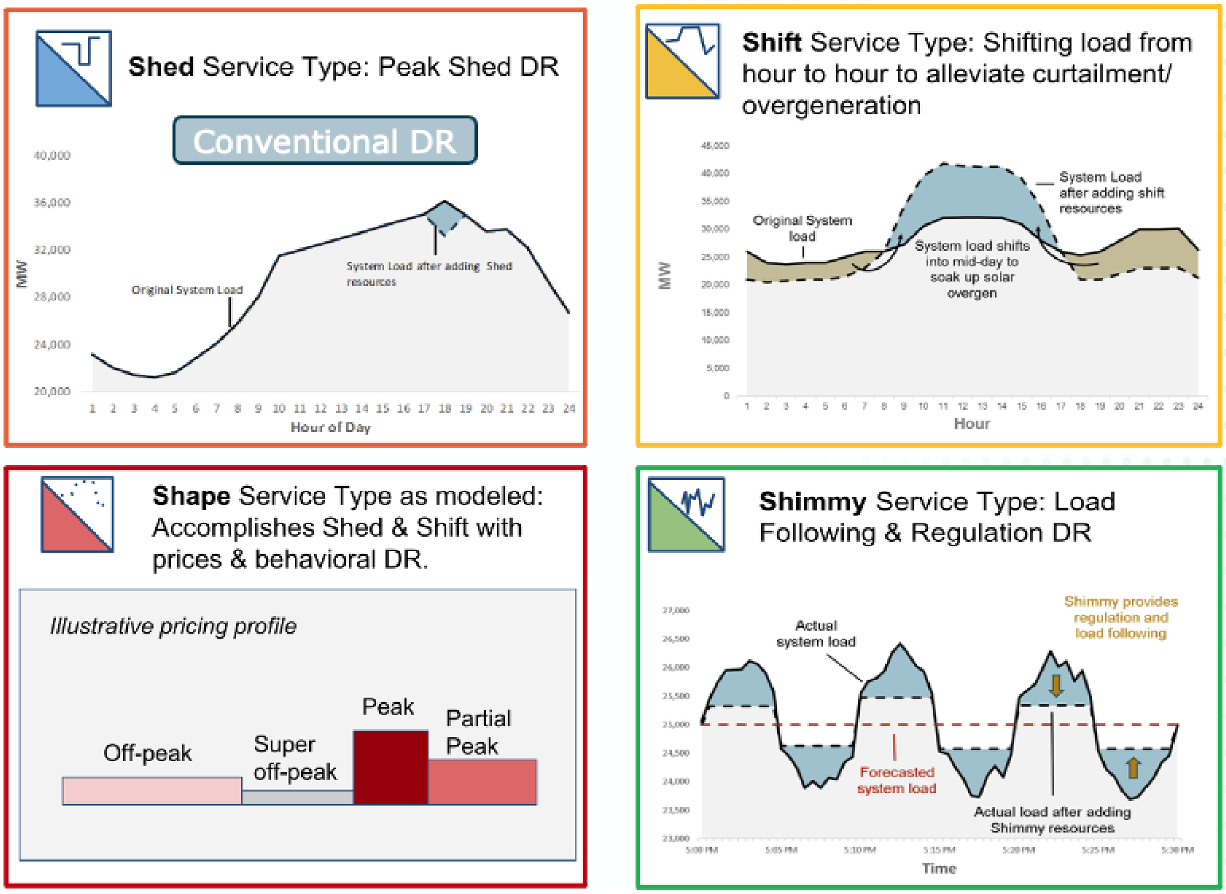

Figure 2. Typology of Demand Response Services

Source: Lawrence Berkeley National Laboratory

Shed: Reduction in power loads during periods of high demand. Can significantly reduce grid peaks and avoid use of expensive and polluting "peaker" power plants. For example, EVs can defer charging when possible to avoid days and times (typically early evening) when grid power reserves are low.

Shift: Shifting load over various time periods to take advantage of low-cost renewable energy or to support other grid power limits including at the distribution level. Here, EVs could charge in midday to use available solar power resources.

Shape: Adjusting demand at local customer levels in response to TOU utility rates, to minimize customer bills. EVs could use built-in timer functions to delay charging to off-peak times, or enroll in charge management programs where this could be more carefully controlled through communication with smart chargers or through vehicle telematics. This is likely to become more important in the future where hourly-varying utility power rates are anticipated.

Shimmy: Short-term adjustments in power demands to follow (reduce) local loads and potentially provide grid frequency regulation services (maintain grid frequency at 60 Hertz). EVs could be programmed to rapidly and automatically move from a charging set point to a different power level to provide valuable regulation up and regulation down services based on a utility control signal.

While the ability of EVs to provide the full range of these grid services has now been well established by various pilot projects and programs, the complexities of implementing VGI involve: a) the ability of EV-owning households to be compensated for these services through direct payments, beyond the reductions to their electricity bills, b) the potential need to connect multiple EVs to create large virtual power plants (e.g., greater than 500 kW, a typical utility size threshold), and c) establishing appropriate communications protocols and codes and standards, particularly for fast-response "shimmy" type services like frequency response.

Bidirectional charging can significantly expand the opportunities for grid benefits. EVs can provide larger load shifting capability than most other DR resources (such as hot water heaters, thermostats, and fans) as well as providing power back to the grid through V2G at opportune times, which makes them a major grid resource, especially as the number of EVs proliferate.

This potential for EVs to use smart charging including V2G has been understood for more than 25 years at this point, dating back to studies in the late 1990s and early 2000s (Kempton et al., 2001; Kempton and Tomic, 2005). The analytical studies have evolved from early analysis assuming small battery pack EVs (<50 kWh) to more recent studies that consider the much larger, longer-range, lithium-ion battery packs of 100 kWh storage capacity or more, offering much larger potential for load shifting and providing V2G power. Whereas many EV owners over the past 15 years have faced some degree of "range anxiety" and have sought to charge their vehicles on a daily basis, modern EVs with 200-300+ mile range may only need to be charged once or twice a week, offering many hours of the week where the vehicles could be plugged in and available to provide grid services while not actively charging.

Studies of Charge Management from Electric Vehicles

Early modeling work explored the ability of EV owners to shift their charging routine, making assumptions about vehicle driver behavior and various grid attributes, while later work has used real-world EV charging data and engaged in more sophisticated analysis of grid operations.

SmartCharge

A 6-month project called SmartCharge led by Honda and eMotorWorks in conjunction with Southern California Edison assessed the ability of EV owners to shift vehicle charging times as well as the capacity of power plants to employ renewable power sources at key times for the grid. The study (Honda, 2018; CleanTechnica, 2018) involved 60 Honda FIT EV drivers (company employees). Each participant was paid $50 to start and $50 every two months for following the program's charge schedule guidance. The study tracked load reduction/consumption, incentives, and customer responses to the program.

Pacific Gas & Electric Company (PG&E) and BMW ChargeForward EV Smart Charging Pilot

PG&E, BMW, Olivine Inc., and UC Berkeley's Transportation Sustainability Research Center partnered on a program called ChargeForward to "demonstrate the technical feasibility and grid value of managed charging of electric vehicles, as a flexible and controllable grid resource." The pilot program, held in PG&E territory, spanned several VGI applications over its two phases. BMW is now carrying the program forward in multiple utility service territories including some outside of California.[2]

The initial ChargeForward project in 2014-2015 focused on DR and load curtailment, with 96 participating EVs. The program used BMW's proprietary aggregation software and vehicle telematics systems, and Olivine Inc.'s grid service optimization algorithms. To minimize disruptions, a second-life stationary battery storage system (100 kW/225 kWh) was used to fill any load gaps for the required 100 kW of DR capacity. During the 18-month trial, the EVs responded to 209 DR events. These DR events are typically 1-3 hours in length and initiated by the local utility in response to strained grid resources. The system met the performance requirements for 90 percent of those events, with an average contribution of 20 percent from the vehicles and 80 percent from the second life battery system (Olivine Inc., 2019). This was an early experiment where drivers could opt-out at any time based on their driving and charging needs.

Building on the successful partnership, ChargeForward 2.0 expanded potential applications in 2016-2018, focusing on: (1) maximizing the use of renewable energy sources while managing customer bills; (2) accounting for residential and away-from-home (mostly workplace) charging; and (3) offering DR grid services for load-curtailment and load-increase, at the both the production and distribution levels. In this second phase the pilot project was expanded to over 400 participants.

This project demonstrated that households could shift their EV charging in response to pricing signals designed to optimized grid resources and to reduce grid costs by up to 20-30 percent in any individual hour. Additional modeling showed the potential to optimize charging to increase renewable electricity utilization by about 1,200 kWh per vehicle per year. Optimizing EV charging to reduce greenhouse (GHG) emissions could potentially eliminate about 300 kg of GHGs per vehicle per year or about 27 percent of current baseline EV emissions. In one test, held during Earth Week, 47 vehicles received more than half of their energy during the day from renewable sources, doubling the number from the prior week.

Figure 3 shows the results of one ChargeForward test case involving optimizing EV charging in both home and away-from-home (typically workplace) locations. The amount of charging (in kilowatt-hours) that was shifted on average from each hour to another time period over the course of the test is shown in red, while the amount of charging added to each hour is shown in green, and the amount that was not shifted is shown in grey. This test demonstrated a high degree of ability by EV owners to shift their charging schedules away from peak evening hours (4-10pm) to hours with lower grid costs and potentially high levels of available renewable energy sources.

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[2] https://chargedevs.com/newswire/bmw-expands-chargeforward-smart-charging-program/

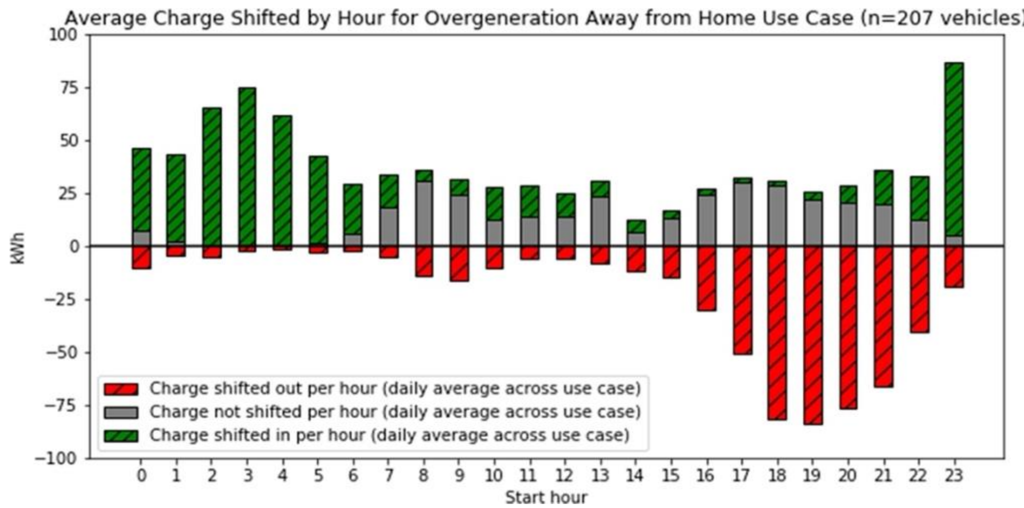

Figure 3. ChargeForward Example Result

Source: Spencer et al., 2021

Studies of Bidirectional/V2G Power from Electric Vehicles

There have also been a series of bidirectional/V2G projects in recent years, typically partnered with or led by utility groups as next-step VGI pilot projects to address distribution-level grid issues. In California, San Diego Gas and Electric Company (SDG&E), PG&E and Southern California Edison (SCE) have active pilot studies and analysis efforts. Some of these efforts are briefly described below.

Los Angeles Air Force Base Vehicle-to-Grid Demonstration

A significant VGI demonstration took place from 2016-2017 at a Los Angeles Air Force Base facility with support from a combination of agencies including the United States Departments of Energy (DOE) and Defense (DOD) and the California Energy Commission (CEC). This demonstration focused on the economic viability of EVs with bidirectional charging capability participating in wholesale markets for electricity. The demonstration used a 15-vehicle fleet with a range of battery sizes, leading to a range of results. Requests to EVs to export electricity to the grid were made based on maintaining a balance between grid power generation and consumption, also known as frequency response. Frequency response is a service that utilities pay for in order to closely maintain grid AC frequency at 60 Hertz, by requesting that generators rapidly turn up or turn down power output as needed.

Gross revenues for the 15-vehicle fleet were $400-1,100 per month ($25-72 per vehicle per month) but net benefits to the facility, once CAISO scheduling fees were included, were positive in only one month out of the10 studied. Typical net losses were a few hundred dollars in the other months (range of $200 to $600 per month) for this small example fleet. Larger fleets may generate more net revenue as they could spread out monthly fixed costs over more vehicles. At the end of the pilot, the DOD decided to discontinue this effort due to the lack of economic viability (CEC, 2018).

Analysis of V2G Opportunities Across Various ISO Territories

An analytical study examining the economic value of V2G-based frequency response services, as well as their potential to reduce GHG emissions, across five Independent Service Operator (ISO) territories over a 16-year period (Noori et al., 2016). ISOs are regional organizations responsible for the overall management of the regional electricity grid. The study found the highest revenues were in New York (NYISO) at up to $42,000 over 16 years (central case, undiscounted) per vehicle, or $2,625 per vehicle per year, followed by the mid-Atlantic region (known as PJM) at $2,375 per vehicle/year, CAISO at $1,688 per vehicle/year, Texas (known as ERCOT) at $1,625 per vehicle/year, and New England (ISO-NE) at $1,125 per vehicle/year. Some regions had relatively higher potential revenue per vehicle, but others had higher total revenue potential because they were larger EV markets.

Figure 4 below presents the box-and-whisker plots from the study, showing the variation is estimated net V2G revenues per ISO area. As shown, projected net revenues are highest for the NYISO territory but with some uncertainty, with PJM in a similar range followed by the other major ISO areas.

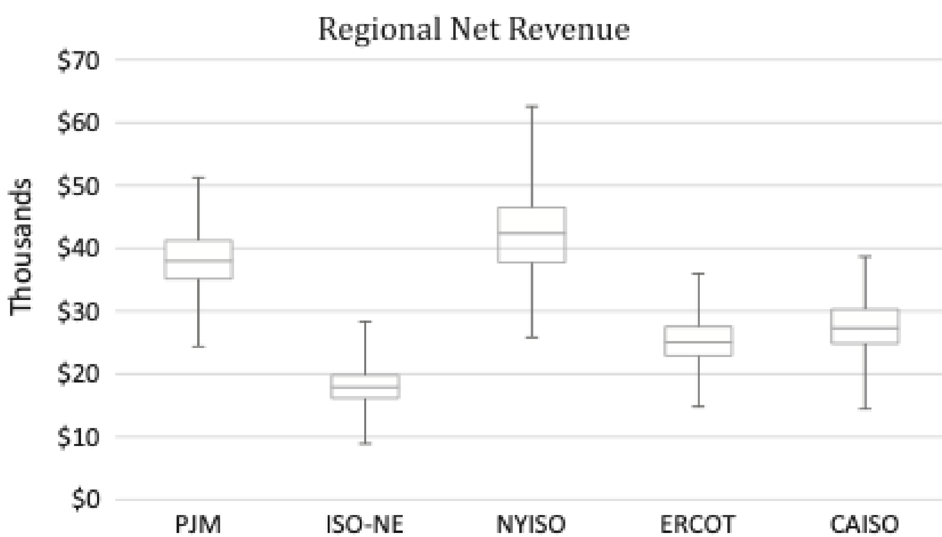

Figure 4. Estimated Net Revenues from V2G Services Over a 16-Year Period

Source: Noor et al., 2016

The SDG&E "Power Your Drive" project, approved by the California Public Utilities Commission (CPUC) in 2016, involved installing over 3,000 chargers at multi-unit dwellings and in disadvantaged communities, as well as workplaces. The program involved an innovative VGI rate "that directly served drivers participating in the program on a dynamic electric rate which encourages drivers to charge when there is ample capacity on the electric grid and renewable electricity generation is generally high." The program included a total of 3,040 energized ports at 254 sites, 1,694 charging ports at workplaces and 898 at multi-unit dwellings. In all, 4,500 EV driver/customers participated and over four million kWh of electricity was dispensed by the end of 2020.

The VGI rate charged to drivers in the project varied from hour to hour based on grid conditions, at both the wholesale and distribution levels. Participants received hourly prices for charging on a day-ahead basis to plan their charging timing. A total of 87 percent of charging from Power Your Drive participants occurred during off-peak hours, compared to 81 percent of off-peak from EV Time-of-Use residential customers and 77 percent of demand response customers. The program demonstrated that drivers were able to alter their charging routine both within the day and across different days.

The VGI base rate recovered the cost of operating the transmission and distribution system and administering Public Purpose Programs, among other costs. The CAISO day-ahead energy price included an additional hourly charge during approximately the top 150 hours of annual demand on the California grid; and a separate hourly charge during approximately the top 200 hours of annual demand on a customer's individual distribution circuit (SDG&E, 2018; SDG&E, 2021).

In a survey of program participants, when asked how often they checked electricity prices before charging their vehicles, 60 percent of drivers (108 of 181 responses) checked "very often" or "sometimes," and 38 percent (68 of 181) indicated they "never" checked prices before charging.

JUMPSmart Maui

Another utility-scale project that has been ongoing for some years and is yielding initial findings is the JUMPSmart Maui project, led by Hitachi with financial support from NEDO in Japan and participation from Hawaiian government agencies and universities. The project started in 2011 and continued through 2016, with two project phases (NEDO, 2017). This demonstration project examined the ability of V2H, or vehicle-to-home, where an EV can provide backup power directly to a home, and V2G to balance loads on the grid using the "Maui Virtual Power Plant" concept for controlled EV charging. Initially the project focused on installing DC fast chargers as a supplement to residential charging on Maui. Phase 2 of the project yielded more information about the potential value to the grid from new V2G applications (Hitachi Ltd., 2018). This second phase involved 306 of the 889 EVs on Maui: 200 households were in the Level 2 V1G charger program while 80 households were in the project Phase 2 V2G pilot program using Hitachi bidirectional chargers and Institute of Electrical and Electronics Engineering (IEEE) 2030.5/SEP 2.0 for control.

The study showed that EV owners had significant ability to shift their EV charging from peak electricity use times (5-8pm) to early morning hours. Overall, based on the charging habits of 80 participants, 14-31 percent of the total capacity of the EV batteries was available to be discharged during the peak hours of 5-8pm, 8-30 percent of the capacity was available during nighttime charging, only 2-4 percent was available during daytime hours, and 6-16 percent was available in the early afternoon. These estimates were based on when vehicles were connected to the grid and their battery state-of-charge during those periods. This suggests both that driver plug-in and mobility behavior are important to V2G potential, and that this potential can be modified by encouraging drivers to plug in even when they do not necessarily need to charge.

EVs as an Alternative to Stationary Battery Storage

An analytical study of the potential to substitute EVs for stationary battery storage for the California grid examined various situations where EVs could offer power support on the gigawatt (GW) scale. It found that VGI could provide a gross value equivalent to $1.45-1.75 billion of 1 GW of stationary power storage. These values come from storing excess renewable energy, typically during peak solar production in the middle of the day, and then providing grid power support in the early evening. The estimated cost of V1G service for 1.0 GW of power was $150 million, yielding a net value range of $1.3-1.6 billion. With the addition of V2G capability by 2025, the estimated gross value increased to the equivalent of $12.8 to $15.4 billion of stationary storage or 5.0 GW of power capacity. The study assumed stationary battery storage could provide $500/kWh whereas these costs may be considerably less in near future, so the values above could be somewhat overstated (Coignard et al., 2018).

Analysis of Grid Benefits of V2G In California

An analysis comparing V2G and smart charging in California examined the costs and benefits of several alternatives including unmanaged charging, managed charging, and V2G under different calculations of potential net benefits. The study considered the potential for V2G to include grid ancillary services in the form of grid frequency regulation. The study was sponsored by the Electric Power Research Institute (EPRI) with participation from the Lawrence Livermore National Laboratory and E3 Consulting. The effort focused on Society of Automotive Engineers (SAE) communication standards but with consideration of open standards as well, for more flexible approaches in the future. The project notably integrated real-world demonstration activities and data collection in conjunction with major automakers along with additional analysis. Possible applications included facility demand management, local and larger grid distribution considerations, system supply balancing, and reverse power flow aspects.

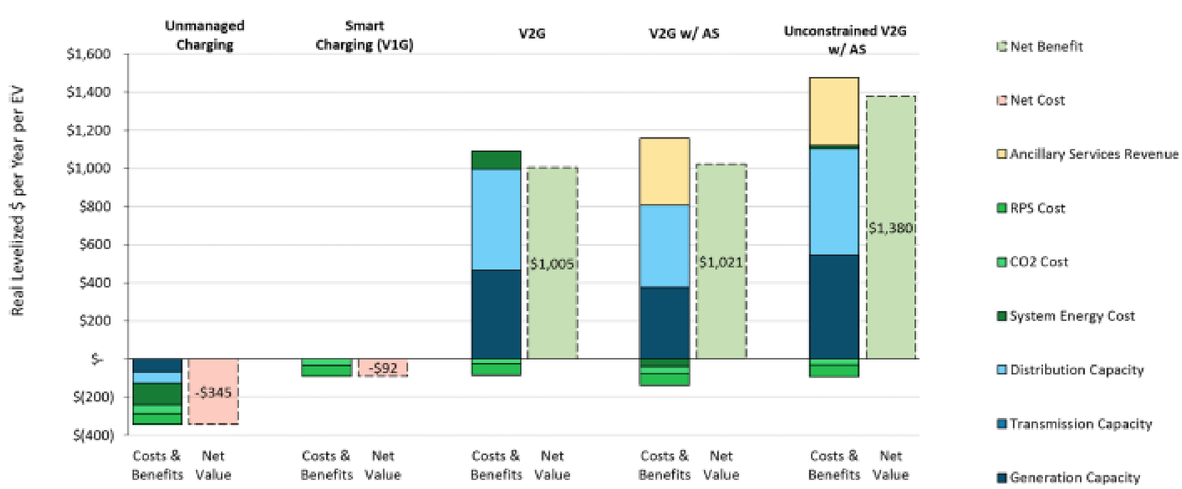

Figure 5. Estimated Costs and Benefits of Smart Charging and V2G Under Utility Control Base Case

Source: EPRI, 2019

Figure 5 shows the base case results of the study, where unmanaged charging yielded net costs on the order of $150 more per year compared to managed charging. The base V2G case yielded net benefits of about $250 per year, or about $500 per year more net benefit than unmanaged charging. When ancillary services are also included (V2G w/ AS), V2G net benefits rose to over $300 per year (Donadee et al., 2018; EPRI, 2019).

In the high value case, Figure 6 shows considerably higher net benefits than the base case particularly for the V2G cases. The high value case assumed higher avoided costs from deferring distribution system upgrades ($120 per kW-year versus $20 per kW-year) representing a theoretical capacity constrained area in Southern California. The basic V2G case shows net benefits of just over $1,000 per year; the value rises slightly when ancillary services are included and reached nearly $1,400 per year in net benefits when battery degradation costs/constraints are removed (EPRI, 2019). These results highlight the much greater potential value of adopting bidirectional V2G power transmission compared to basic charge management.

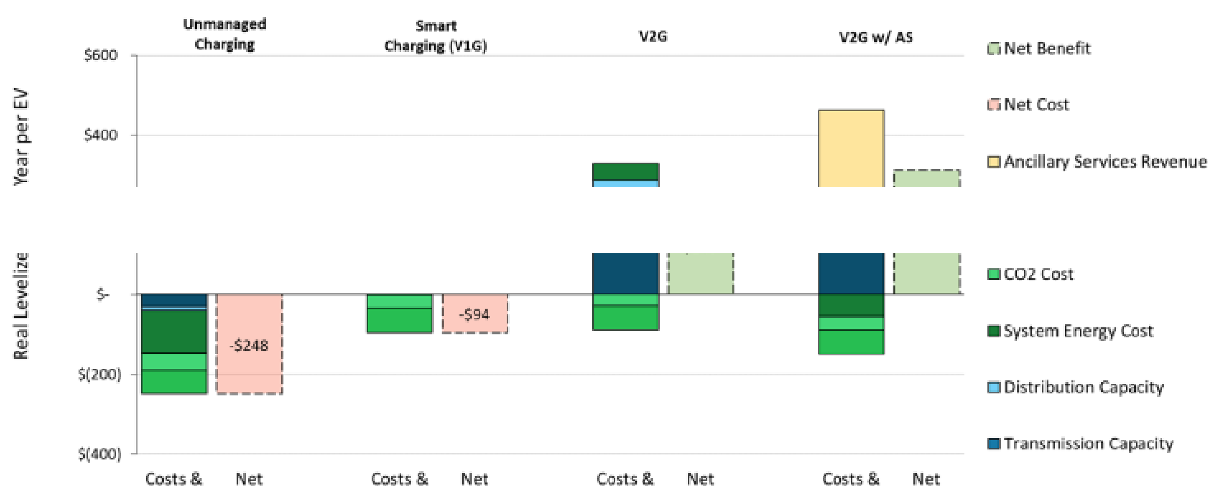

Figure 6. Estimated Costs and Benefits of Smart Charging and V2G Under Utility Control High Value Case
Source: EPRI, 2019

Summary of Advanced VGI/V2G Studies

V1G and V2G value research, including both conceptual studies and a growing number of real-world studies, is yielding a more nuanced understanding of VGI values that can be realized. Projected net revenues are highly variable depending on the particular VGI application. These are positive in many cases, especially beyond the near-term, suggesting that as more streamlined approaches to monetize VGI services appear in the marketplace, more sustainable business models around these services appear to be possible. The costs of aggregation service providers/ISO scheduling coordinators are a significant expense in the near-term for some markets. The ISOs require authorized scheduling coordinators to bid services into their markets, along with aggregators to bundle enough individual customers (if small such as EV owners) to reach power level thresholds for market bids. The fees that these groups charge can significantly erode or even erase program benefits; this is a key area for streamlining in the future. A general conclusion is that V2G applications have two to three times the value of managed charging, but present considerable additional complications related to grid integration and site-specific implementation costs.

Dynamic Pricing Concepts for Grid Electricity

Successfully implementing managed charging and bidirectional power transfer will require utilities to establish rate schedules that send appropriate price signals to customers. In fact, electricity rates for consumers in California have evolved considerably in recent years. Historically, residential customers paid for electricity with tiered rates that would escalate based on the amount of electricity used. Commercial customers would pay more complicated rates based on both the energy (kWh) used as well as a demand charge based on the peak amount of electricity used in a given month.

More recently, utilities have been offering a variety of TOU rates where rates are tied to specific times of day, typically highest in the 4-9 pm interval when grid demands are peaking. Off-peak rates are lower. The greater the differential between peak and off-peak rates, the more likely consumers will respond based on potential bill savings.

The next step is charging electricity consumers the actual costs of serving them with dynamic rates that vary hour by hour or even more frequently. The CPUC has recently proposed a rates concept known as California Flexible Unified Signal for Energy (CalFUSE). This would include real-time pricing as well as mechanisms for customer-owned distributed energy resource (DER) appliances to more fully participate in power markets by providing compensation for exporting electricity to the distribution system.

The CalFUSE proposal calls for a new approach to demand flexibility by more explicitly signalling to utility customers time-based variations in grid electricity costs. The "CalFUSE Framework" would include presenting customers with dynamic rates, additional elements of rate reform, and enhanced mechanisms for customer options to manage and optimize their electricity usage and minimize their utility bills.[3]

[3] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf

The 10 CPUC Rate Design Principles:

1. Low-income and medical baseline customers should have access to enough electricity to ensure basic needs (such as health and comfort) are met at an affordable cost.
2. Rates should be based on marginal cost.
3. Rates should be based on cost-causation principles.
4. Rates should encourage conservation and energy efficiency.
5. Rates should encourage reduction of both coincident and non-coincident peak demand.
6. Rates should be stable and understandable and provide customer choice.
7. Rates should generally avoid cross-subsidies, unless the cross-subsidies appropriately support explicit state policy goals.
8. Incentives should be explicit and transparent.
9. Rates should encourage economically efficient decision-making.
10. Transitions to new rate structures should emphasize customer education and outreach that enhances customer understanding and acceptance of new rates and minimizes and appropriately considers the bill impacts associated with such transitions.

Figure 7. CPUC Rate Design or "Bonbright" Principles

The CalFUSE Framework references the 10 CPUC rate design principles that have been in place for many years. These are shown in Figure 7 and represent a commitment to conservation, equity, and marginal cost-based pricing.

The underlying premise of the CalFUSE concept is that TOU rates are not sufficiently scaled to achieve the full benefits of flexible load management. A study cited by CPUC indicates that an analysis of SDG&E rates in 2019 showed that 57 percent of the highest priced wholesale grid intervals fell outside of the top TOU retail rate periods. TOU rates also do not reflect the very low cost of grid power at certain times of the day when excess power is being generated by renewable resources, thus blunting the opportunities for, or willingness of, customers to shift demand to those periods. Hence, customers are not being made aware of the realities of varying grid costs, even with TOU rates, and the CalFUSE concept aims to help bridge that gap.

Through the CalFUSE concept, CPUC aims to advance dynamic rate policy in California by: 1) developing standardized and universal access to real-time utility rates using a concept known as the Market Informed Demand Automatic Server (MIDAS); 2) introducing dynamic prices based on wholesale grid costs; 3) incorporating capacity charges based on real-time grid use; 4) expanding access to costomers to sell electricity back to the utility at the same real-time, locationally specific rates as they are being charged; 5) offering subscription services that would give electricity ratepayers a predictable bill based on their own specific power needs, while also allowing flexibility to increase their use where beneficial; and 6) implementing additional "transactive energy" options where customers may be able to import or export electricity based on pre-determined rates in order to provide an additional tool for energy management. Figure 8 shows an overall format for the CalFUSE concept, including setting real-time prices, import/export at those current prices, fixed price and forward contracts as enhancements, and the role of local load management devices to provide grid-responsive load management.

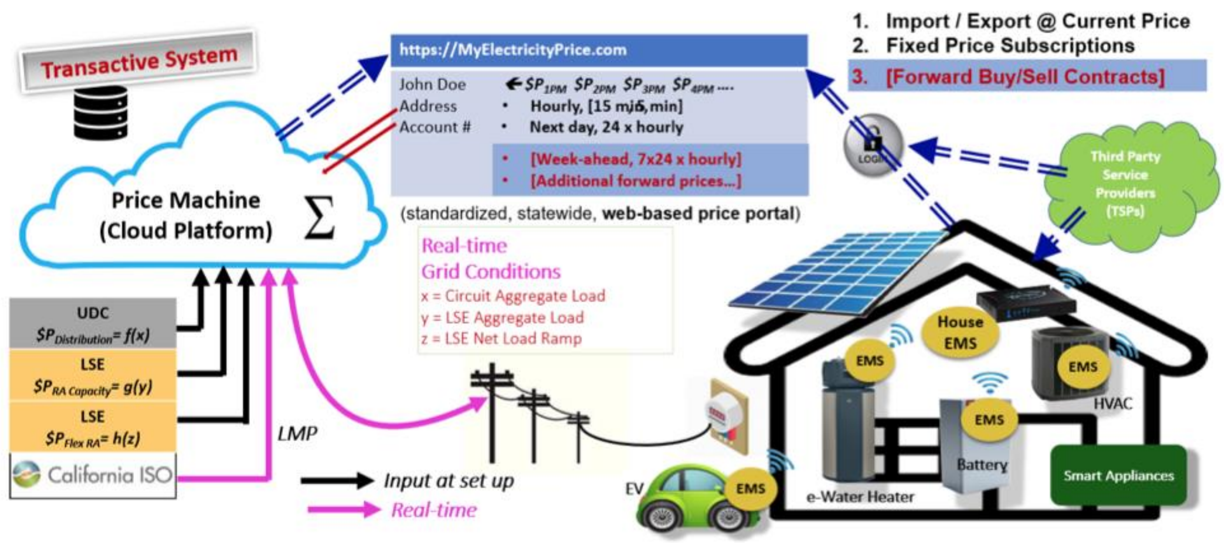

Figure 8. CPUC CalFUSE Concept for Dynamic Utility Rates

Source: CPUC

The major California Investor Owned Utilities (IOUs) are now conducting pilot programs using dynamic rates, at least partly in response to the CEC's load management standards rulemaking in 2022. The new rules are intended "to encourage electricity customers to shift electricity demand away from high demand periods, when peaking power plants and other polluting generators are in use, to times when lower-cost clean electricity is available. Utilities and state programs can incentivize this shift through electricity rates that reflect actual grid conditions."[4] The CEC rules require utilities to offer at least one customer rate that varies on at least an hourly basis, to be implemented by 2027. The PUC extended PG&E and SCE program authorizations in early 2024 with a goal of enrolling at least 50 MW of load in each rate programs by the end of 2027.[5] The PG&E programs target 50 MW of agricultural customers and 50 MW of a total of commercial, industrial, and residential customers. The SCE program also targets 50 MW of a total of commercial, industrial, and residential customers. These programs specifically include eligibility of EV loads and VGI for charge management. The PUC is asking SDG&E to re-submit its proposed real-time pricing pilot proposal, with expected approval and implementation in late 2024.

[4] https://www.energy.ca.gov/sites/default/files/2022-10/Load_Management_Fact_Sheet_ADA.pdf

[5] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-flexibility-oir/pilot-expansion-2024.pdf

California Grid Management and VGI

As a practical matter, achieving benefits from VGI will require coordination between energy suppliers and distributors, and participating EV owners. In California, CAISO is responsible for the overall management of the state's regional electricity grid as what is known as a regional transmission operator (RTO) or independent system operator (ISO). There are several such authorities in the United States as shown in Figure 9 below.

Figure 9. Independent System Operator Regions in the United States

Source: FERC, 2023

In California, there are several electric utilities or load-serving entities (LSEs) that deliver electricity to end users at service voltages of typically 240-480V (higher for larger commercial and industrial facilities). These are either for-profit IOUs or MOUs, which typically offer lower electricity rates than the IOUs.

The landscape of electricity service providers in California is complicated, with a network of IOU and MUD territories interlaced with community choice aggregation (CCA) providers that can offer alternate power plans to the main utilities, while relying on the utility-owned physical distribution infrastructure. CCAs contract for power supply on behalf of their members, which is itemized separately on a consumer's bill from the delivery charges levied by the IOU. The CCA movement was initiated by the passage of Assembly Bill 117 in 2002. There are 25 operational CCA programs in California serving more than 14 million customers in more than 200 cities and counties throughout the state. Figure 10 below shows the areas served by IOUs, MOUs, and CCA groups—in the case of IOUs and CCAs in an overlapping fashion depending on customer choice.

Figure 10. Major Utility Service Providers and Community Choice Aggregators in California

Source: CALCCA

There are serious concerns about local stresses on utility grids and the need for grid upgrades to support increasing loads, including those from EVs. Estimates of the cost to upgrade the distribution grid in California through 2035 to support new electrical loads including EVs are as high as $50 billion.[6]

Evolution of the California Net Load or "Duck Curve"

In managing the state's power grid, CAISO must balance supply and demand on a fine timescale to avoid disturbances in grid frequency, which must be maintained at a cycle timing of 60 Hertz. They do this by contracting with electricity generators to turn up or down the amount supplied (frequency regulation up or down) to correct any instantaneous mismatch between demand and supply using a concept called "area control error" or ACE. ACE must be kept within acceptable bounds to avoid frequency drifting off to a point where sensitive electronic devices can be negatively affected. EVs that are connected to the grid can also provide this service, as demonstrated by pilot programs in Denmark and Norway as well as the United States, by supplying stored electricity when demand is high or absorbing excess electricity when demand is low.[7]

[6] https://www.utilitydive.com/news/california-50b-2035-grid-ders/650242/
[7] See: https://nuvve.com/nuvve-circle-k-deploy-grid-services-ev-fast-chargers-norway-denmark/

CAISO must also be prepared to manage the rapid fluctuations in electricity customer demands, daily trends in demand, and sudden shutdowns in generators due to unscheduled maintenance events. In California the "duck curve" in Figure 11 below illustrates what is known as the "net load curve." This curve describes the amount of electrical load in the state that must be made up from fossil fuel-based generators or other sources after all the "must take" renewables are accepted onto the grid. The order in which different sources of electricity are accepted onto the grid is known as the "loading order." The California loading order was outlined in a 2003 Energy Action Plan, where renewables are the highest priority resources that must be used or "taken" first before other types of generation such as natural gas power plants, in order to minimize grid emissions.[8]

The first criteria of the loading order is to use energy-efficient technologies and utilize DR where possible, to reduce demand. The second priority is to accept electricity from renewable energy sources along with distributed generation, including local combined heat and power plants that are more efficient than large-scale generation. These are the ones known as the "must take" resources. Finally, what the state calls "clean and efficient fossil fuel generation" sources are used to make up the remaining electrical supply needed to meet demand. The state also has one operating nuclear power plant at Diablo Canyon that operates continuously.

Figure 11 shows the evolution of the net load curve from 2015 through 2022. As shown, the "belly" of the duck has grown larger over time to the point where on average the state now produces enough electricity through non-fossil fuel means to avoid or nearly avoid the need for additional electricity generation in the middle of the day. However, there is a steep ramp down in the morning hours, meaning fossil fuel generation has to decrease as well, and then there is an even steeper ramp up in the early evening when the sun is setting, where generation has to increase rapidly. This is where a more agile type of natural gas generators known as "peaker" plants comes into play, compared with other types of "baseload" natural gas plants that operate more continuously. Peaker plants can ramp up and down quickly, but are typically less efficient and more polluting that baseload generators.

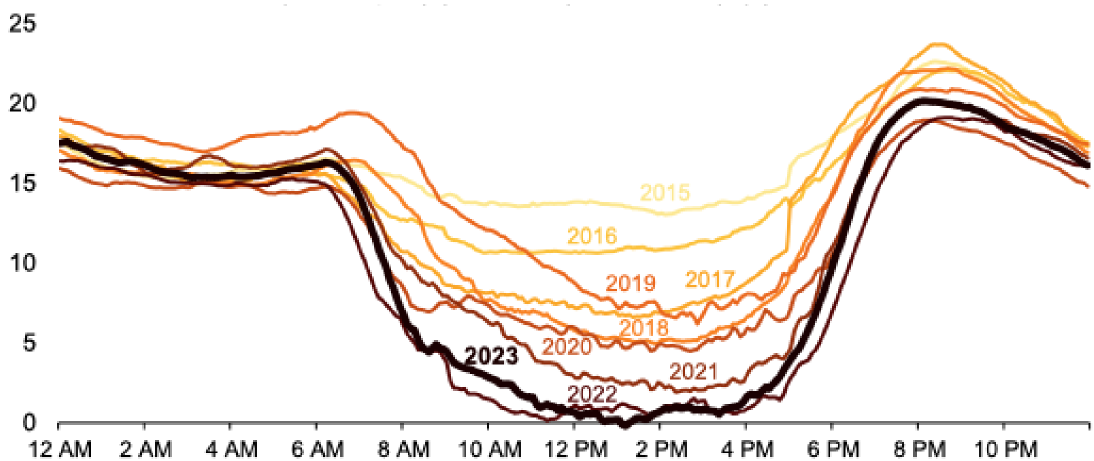

Figure 11. Evolution of California's Net Load or "Duck Curve" (in Gigawatts)

Source: CAISO, 2023

[8] See: https://docs.cpuc.ca.gov/word_pdf/REPORT/28715.pdf

EVs can potentially provide several services to CAISO to meet its objectives. These include frequency regulation, “valley filling” by absorbing renewable energy in the middle of the day, ramp rate mitigation, and additional schedule changes in demand that can help CAISO to balance the grid. As described above, frequency regulation is needed to maintain AC grid cycle frequency at 60 Hertz, with very short response times (a few seconds). Valley filling involves shifting EV charging to the middle of the day where it might otherwise have been done in the evening or overnight, and similarly ramp rate mitigation involves avoiding EV charging during the steep early evening ramp period seen in the “neck of the duck” and shifting charging to time where the grid is less strained. These shifts in charging require drivers to be plugged in at the appropriate times, of course, and can be accomplished either by sending signals to start and stop charging to the vehicle chargers (if they are wi-fi enabled) or directly through vehicle telematics systems.

CAISO VGI Activities

CAISO has a long history of engagement with the integration of distributed energy resources (DERs) and has been investigating VGI concepts for about 15 years. DERs include a range of distributed electricity generating and storage technologies including solar photovoltaics, small wind turbines, stationary batteries and others, now including EVs as well. CAISO has concluded four phases of a process known as the Energy Storage and Distributed Energy Resources (ESDER) stakeholder initiative. The phase that was most directly concerned with the participation of EVs as DERs was ESDER3, which concluded in 2019. This effort examined the participation of EV charging stations as demand response resources.

In ESDER3, CAISO proposed to include vehicle charging loads as potential “proxy demand resources.” These resources are aggregations of multiple DR sources that can be grouped together for purposes of bidding DR services into CAISO markets. A key issue with this concept is what types of charger metering and telemetry are required for allowable participation.

In the ESDER3 guidance, host sites must establish a baseline for charger loads from which they can then demonstrate “demand response energy measurements” by reducing loads. For non-residential chargers, customers can use the “ten-in-ten” baseline methodology. Residential chargers may use either the ten-in-ten or a five-in-ten methodology. A ten-in-ten baseline consists of examining customer loads for all 10 of the previous 10 days, whereas a five-in-ten baseline would examine five of the highest load days in a 10-day window prior to the start of the DR events.

In general, EVs are not ideal for DR program participation as they are not consistently available for load reduction at peak times, unlike air conditioners or electric water heaters. Given the generally flexible nature of EV charging, good rate design should shift charging to off-peak hours and thus create a baseline near zero, meaning that there is little or no peak-time load to reduce.

A few pilot programs, including those discussed later in this report, have resulted from the CAISO process, but no major DR programs have been established. CAISO’s ESDER process has now concluded and has moved into a different phase known as the Energy Storage Enhancement process, which is considering additional complexities with electricity storage systems participating in CAISO processes including grid frequency regulation services.

CPUC VGI Activities

The California Public Utilities Commission (CPUC) regulates investor-owned utilities in California, including both electrical and gas utilities, most notably PG&E, SDG&E, SCE, and SoCal Gas, as well as communications networks, transportation network companies, and other regulated industries.

CPUC has been actively engaged in VGI for many years, most notably recently in 2018-19 with a series of VGI workshops convened by GridWorks and involving a wide group of stakeholders including automobile companies, grid services companies, private consultants, academics, and representatives of investor-owned and municipal utilities.[9]

The working group concluded that the following VGI applications were the most potentially valuable:

- Light-duty vehicle applications in the residential sector
- Commercial workplace sector light-duty vehicles
- Customer bill management
- Utility system distribution upgrade deferrals
- Home and building backup power
- Commercial sector demand-charge management (customer bill management)
- Near-term V2G applications
- System applications easily implementable for vehicle locations with daytime charging ability
- Vehicle types with excess battery capacity relative to duty cycle, such as school buses, and
- All system and customer applications that defer charging away from peak periods.

Participants in the working group were asked to estimate the annual value of various VGI services at a statewide level. The results are shown below in Figure 5, where the two highest value applications at $20 million per year were customer bill management and providing real-time energy at a system level. Providing day-ahead energy at the system level was estimated to have annual value of about $12.5 million, followed by grid upgrade deferrals at $10 million per year. Additional applications with lower estimated values are also shown in Figure 12.

[9] https://gridworks.org/wp-content/uploads/2020/09/GW_VehicleGrid-Integration-Working-Group-1.pdf

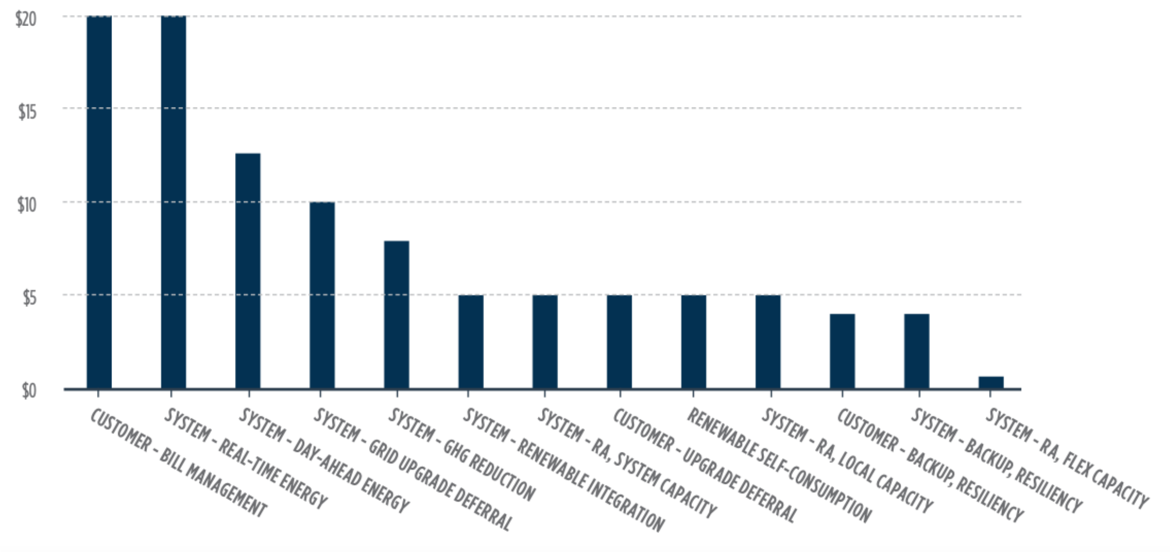

Figure 12. Light-Duty Vehicle VGI Use Case Estimated Average Value in California ($ millions/year)

Source: GridWorks

California Energy Commission (CEC) VGI Activities

The CEC has also been involved in VGI development in California for many years. The agency has provided millions of dollars in funding for VGI research and demonstration projects through its Clean Transportation Program, formerly called the Alternative and Renewable Fuel and Vehicle Technology Program. The CEC has supported the 2014 VGI Roadmap effort led by the CPUC, funded various projects on EV charge management, and funded demonstration projects for V2G-enabled school buses. The CEC's most recent action was approving a $3 million award in March 2024 to install 21 125-kW CCS-enabled bidirectional chargers on at least 20 electric school buses (see Appendix for a detailed description of CCS). The focus of this project is to improve the economics of electric school bus adoption and to potentially provide reliable electricity during power interruptions.[10]

Federal Energy Regulatory Commission (FERC) Actions

The Federal Energy Regulatory Commission (FERC) regulates wholesale power transactions across state lines. In a significant action for distributed energy resources (DERs), including EVs, issued Order 2222 on September 17, 2020 to "better enable [DERs] to participate in electricity markets run by regional grid operators" (FERC, 2023). Order 2222 permits aggregating many small DERs (which could be or include agglomerations of EVs) to participate in electricity markets designed to include relatively large blocks of power resources, well beyond what any single DER facility could provide. FERC suggests that in addition to garnering direct revenue from participating in such markets, DERs could provide

[10] https://www.latimes.com/b2bpublishing/business-announcements/story/2024-03-21/ca-energy-commission-awards-3-million-grant-for-vehicle-to-grid-bus-project-to-serve-students-in-california-districts

additional benefits related to enhancing electricity reliability, reducing emissions, and lowering the overall costs of electricity delivery. These services could be compensated in various ways, such as being paid to reduce grid demands at key times and for particularly impacted locations, and/or selling greenhouse gas emission reductions into carbon trading markets.

FERC Order 2222 is designed to allow DERs better access to regional markets through an aggregator intermediary that would be the direct interface with the ISO/RTO markets. Figure 13 shows a conceptual scheme for this type of market participation.

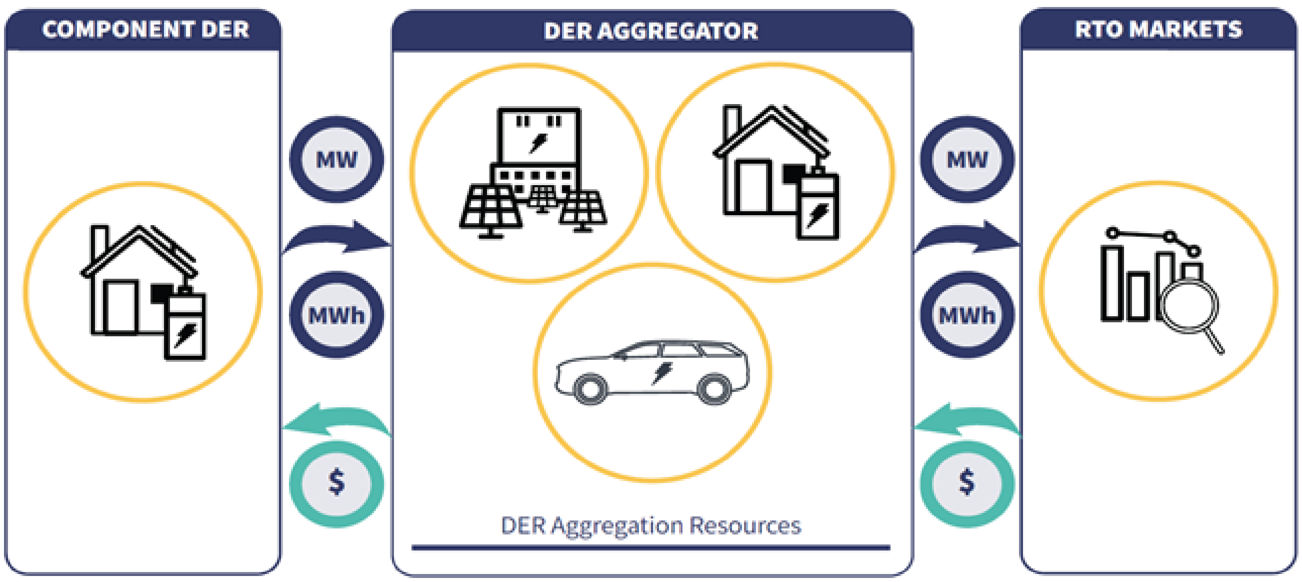

Figure 13. DER Market Participation as Envisioned by FERC Order 222
Source: FERC, 2023

FERC Order 2222 allows DERs to potentially be simultaneous retail customers of local utilities, purchasing power when needed, while also participating through aggregators to sell power in wholesale markets. Historically, ISO market rules have minimum size and performance requirements with which individual DERs were not able to comply. There also are metering and telemetry requirements that pose additional barriers to DER participation.

Following the establishment of Order 2222, ISO/RTOs in the United States have submitted plans to comply with the order. These filings are contending with several important and challenging issues, which include (FERC, 2023):

1) How geographically close each DER in an aggregation would need to be to the others to feed their output into the same location on the ISO/RTO grid, called a "node;"
2) The rules for simultaneous participation by a DER both in retail programs offered by a distribution utility (such as solar net metering, community solar, and utility demand response programs) and in wholesale markets through an aggregator, that prohibit

duplicative compensation for the same services but that currently lack clear definitions and boundaries; and

3) Metering and communications requirements so that the output from DERs can be captured as accurately as necessary to ensure appropriate compensation and facilitate ISO/RTO planning and reliance on DERs, but that can add significant cost and adversely affect project economics.

CAISO is further along than other ISOs in implementing Order 2222 based on its lengthy ESDER process discussed above. Part of CAISO's filing was accepted by FERC in June 2022, but it has requested a two-year delay for full implementation (FERC, 2023). CAISO has indicated plans to modify its programs in response to Order 2222 but stresses that it already allows DER participation in its markets. Proposed changes include modifying certain administrative definitions to align with FERC requirements, implementing a heterogenous DER agreement program (i.e., allowing multiple types of DERs to be aggregated), reducing the minimum resource size for DER participation from 500kW to 100kW, establishing rules against double-counting resources, and additional potential measures (CAISO, 2022). Additional market rules and definitions for the California market are expected to be available around Summer 2024.

Regulatory and Policy Issues and Recommendations

The following are a series of recommendations for how California can further develop VGI capabilities from the vehicle fleet for the benefit of the state electrical grid and general population. The recommendations focus on actions available at the state level, with additional broader considerations included in the report conclusion section to follow.

Recommendation 1: Encourage Automotive Companies to Include V2G Capability in Their EV and PHEV Models

- The California Legislature has now enacted SB 59 (Skinner) into law that requires state agencies to consider requirements for automakers selling EVs in the state to include bidirectional power capability. Given the relatively low cost of this feature, and the large potential that it has for both critical backup power and grid support,[11] we recommend requiring this capability for all EVs sold in California after 2030
- The state should also consider incentives to help EV drivers with medically necessary devices to use their EVs for emergency backup power, as well as helping to enable V2G for other emergency power needs.

Recommendation 2: Include EV-Based V2G in the California Self-Generation Incentive Program

- The state should permit eligible households to receive incentives for connecting EV batteries under the California Self-Generation Incentive Program, where they can be shown to provide similar benefits as stationary battery systems.

Recommendation 3: Allow EV Owning Households to Participate in More than One Utility DR Program

- Households should be able to participate in one or more DR programs that all contribute to reducing loads on the grid during key times.

[11] https://www.sfchronicle.com/opinion/openforum/article/california-electric-vehicle-blackout-18331565.php

- Households with more than one controllable/flexible load should be given a single interface with the utility or selected aggregator to enroll as many of their relevant household loads as possible in a unified program.

Recommendation 4: Support the Use of Onboard EV Inverters for Grid Interconnection

- The state should support broader efforts to enable onboard inverters to be certified for grid interconnections using the AC interfaces on the vehicles, obviating the need for duplicate inverter systems.

Recommendation 5: Establish State VGI Targets for 2030 and Beyond

- To further develop the potential of VGI, the state should adopt targets such as the number of EVs enrolled in managed charging programs and/or total installed capacity for bidirectional chargers, or other appropriate metrics.
- Similar to state procurement targets for battery-based storage in utility service territories, California could require IOUs (and encourage MOUs to similarly participate) in programs to establish a minimum number of bidirectional chargers and enrolled vehicles needed to provide important grid support to benefit electricity ratepayers.
- These target levels could be established through workshops with stakeholders, convened by the relevant state agencies (CPUC, CEC, and CAISO) and including utility groups, automakers, charger manufacturers, third-party aggregator groups, consumer ratepayer advocates, and other interested parties.

Conclusions and Future Research

The state is nearing two million EVs, which is starting to strain the state's electricity grid, but also could potentially provide a valuable energy resource. The current fleet of EVs in California represents approximately 100 gigawatt-hours (GWh) of battery storage and 20 GW of power load at an average of 10 kW per vehicle. EVs are unusual power users for utility grids as they are both relatively large (in a household context)

The concepts of VGI and V2G have been known for decades, but the proliferation of EVs in global markets is now making their potential a reality. EVs are already participating in a range of utility and aggregator programs to benefit utility grids, and evolving regulatory and policy development can further unlock this potential. Additional emerging applications include using EVs for emergency backup power, further participation in wholesale power markets, and better managing power demands on impacted distribution feeders.

A general conclusion that can be drawn from the various studies conducted to date is that V2G uses can generate two to three times the value of managed or "smart" charging. However, there are considerable additional complications for V2G implementation, and variable and site-specific implementation costs. Some cost savings such as deferring distribution system upgrades can be very significant but are also site-specific. These values depend on the level of current and projected congestion on the individual distribution feeder lines and are therefore difficult to predict.

Future research on this topic is warranted in several key areas, given the clear potential of managed EV charging to help mitigate the adverse impacts that might otherwise be expected from unmanaged charging. Important areas include better understanding EV driver behavior and willingness to participate in managed charging and V2G programs, establishing value-adding activities in specific power system markets and locations, and opportunities for policy development to further enable this potentially important concept for grid modernization.

Important Definitions

As in many specialized fields, there is a considerable amount of terminology and jargon used in the VGI field. These terms are used somewhat loosely and at times this seems to create some confusion. Below are definitions of the key terms and acronyms used in this report and that are suggested for broader uses.

Concept	Definition used
BEV	Battery electric vehicle: vehicles that operate solely on battery power with an electric motor.
CAISO	California Independent System Operator: operates the California electricity transmission grid, balances power generation and demand in real time, and provides other ancillary services for grid system stability.
CCA	Community choice aggregation: CCA organizations are regional entities that provide electrical grid customers alternative rate plans from their primary host utility company, including green/renewable rate plans and other energy efficiency related programs.
CharIN	The Charging Interface Initiative Inc.: CharIn is the leading global association with over 300 international members dedicated to promoting interoperability based on the Combined Charging System (CCS) and the Megawatt Charging System (MCS) as the global standard for charging vehicles of all kinds.
CPO	Charge point operator: these include ChargePoint, EVgo, Tesla Supercharger, Electrify America, Blink Charging, and others. These are the entities that operate a network of charging stations and have contracts with electricity service providers to allow their customers to use the charging facilities.
CSMS	Charging station management system: Manages charging stations and has the necessary information to authorize users to use its charging stations.
DER	Distributed energy resources: Devices that generate energy on a smaller scale than full sized grid generators (e.g., solar photovoltaic systems or combustion-based generators), or store energy (e.g., stationary battery storage systems or

	vehicle batteries), or are otherwise able to respond to utility grid conditions such as devices embedded in distribution grids (e.g., electric vehicle chargers, smart thermostats and fans).
DLM	Dynamic load management: refers to optimizing a property's electricity loads (including EV charging) to optimize power use for grid operations or utility customer bill benefits.
DR	Demand response: Changes to customer electricity usage (typically reducing use or shifting use to other times in the day) at certain times in response to economic incentives, price signals, or other conditions
DSO	Distribution system operator: Regional utilities that operate the electrical distribution grid, also known as load-serving entities (LSEs).
EMS	Energy management system: A device local to a site that manages the electrical and thermal loads (and/or generation) based on local and/or contractual constraints and/or contractual incentives.
EV	Electric vehicle: typically synonymous with BEVs that operate solely on batteries but may include plug-in hybrid vehicles (PHEVs).
EVSE	Electric vehicle supply equipment: Supplies electricity to an electric vehicle. Commonly called charging stations or charging docks, they provide AC or DC electric power to the vehicle that is used to recharge the vehicle's batteries.
FERC	Federal Energy Regulatory Commission: The United States government agency that regulates the transmission and wholesale sale of electricity in interstate commerce.
IOU	Investor-owned utility: for-profit electrical or other fuel-provision corporations that are privately-owned but still subject to PUC oversight and regulations as natural monopolies
LSE	Load serving entities: electric utilities that provide electrical services to residential, commercial, and industrial customers either as investor-owned, municipal, or other regulated entities

MOU	Municipal owned utility (also known as municipal utility district or MUD): MOUs are not-for-profit municipal utility districts that provide electricity (or other fuels or water) and that are governed by municipal boards.
NEM	Net energy metering: programs that accept power from local sources such as rooftop solar energy systems, stationary batteries, or EVs where customers are metered and compensated for the power that they supply to the local electricity grid
OCPP	Open charge point protocol: an application protocol for communication between EV charging stations and a central management system
Open ADR	Open automated demand response: an open-source protocol to send information and signals to cause electrical power-using devices to be turned down or off during periods of high demand
PEV	Plug-in electric vehicle: A term that incorporates PHEV and BEV
PHEV	Plug-in hybrid electric vehicle: vehicles that operate on both electricity and liquid fuels (e.g., gasoline) with serial or parallel configurations using both electric motors and combustion engines
PKI	Public key infrastructure: A tree-like, hierarchical structure of Certificate Authorities
SAE	Society of Automobile Engineers: a global association of engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries whose core activity is developing consensus standards
VGI	Vehicle-grid integration: Refers to the process of integrating EVs with electrical grid infrastructure, encompassing charge management or smart charging, provision of grid ancillary services, and vehicle-to-grid power
V2G	Vehicle-to-grid: Refers to bidirectional use of power from electric vehicles to support utility grid or local loads (sometimes also referred to V2H for vehicle-to-home or V2B for vehicle-to-building)

Appendix A: Recent California Legislation for Vehicle-Grid Integration

The topic of VGI has gained recent attention from legislative bodies as well as industry groups and government agencies. In California, a few recent pieces of legislation have been proposed, and in some cases enacted, relating specifically to EVs and electrical utility grids. These are briefly summarized below.

SB 676: Vehicle-Grid Integration

Senate Bill (SB) 676 was introduced by Senator Bradford in early 2019 and subsequently passed into law later that year. This is the most important piece of California legislation on the topic of VGI to become law, with multiple provisions regarding the establishment of cost-effective VGI practices, assessment of potential impacts on ratepayers, and reporting requirements for investor-owned utilities (IOUs), other load-serving entities (LSEs) and community choice aggregation (CCA) providers.

The IOUs operating in California are Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric. Additional LSEs include municipal utilities such as Los Angeles Department of Water and Power, Sacramento Municipal Utility District, and rural electric cooperatives. These entities may or may not own and operate electricity generating plants, but they operate transmission and distribution systems to deliver power to end users. CCAs provide special rates to customers who wish to use high levels of renewable power but rely on the LSEs for physical delivery of electricity.

SB 676 defines electric vehicle-grid integration as: “any method of altering the time, rate, or location at which the EV charges or discharges, in a manner that optimizes an EV’s interaction with the grid and provides net benefits to ratepayers by doing any of the following: a) increasing grid asset utilization; b) avoiding distribution infrastructure upgrades; c) integrating renewable energy resources; d) reducing the cost of electricity supply; and/or e) offering reliability services.”

The law amends Section 740 of the California Public Utilities Code to:

1) The CPUC, by December 31, 2020, must establish strategies and quantifiable metrics to maximize the use of feasible and cost-effective EV-grid integration by January 1, 2030. The strategies shall be applicable to IOUs, electric service providers (ESPs), and CCAs, and must be consistent with the following:
    a) Strategies must account of the effect of time-of-use rates on electricity demand from EV charging.
    b) Expenditures on EV-grid integration must be in the best interest of ratepayers.
    c) EV-grid integration strategies must reflect electrical demand attributable to EV charging, including from existing programs.

d) EV-grid integration must be consistent with existing transportation electrification goals.

e) The CPUC must consider incorporating the United States National Institute of Standards and Technology's reliability and cybersecurity protocols or a similarly protective set of cybersecurity protocols.

2) Each publicly owned utility that files an integrated resource plan update with the California Energy Commission (CEC), the state agency that sets energy use standards, forecasts energy use, and funds energy research and development, must consider the following:

a) Establishing EV-grid integration strategies that are in the best interest of ratepayers and reflect the publicly owned utility's estimated electrical demand resulting from EV charging.

b) Evaluating how its existing and planned EV-grid integration program, including rates and transportation electrification investments, further EV grid integration strategies it has established.

3) The CPUC must reference the EV-grid integration strategies in future transportation electrification proceedings, consider how EV-grid integration can defer infrastructure costs and provide other benefits, and identify how investments will advance the strategies.

4) Each community choice aggregator must annually report to the CPUC how its current and planned rates, programs, and investments further EV-grid integration strategies.

5) Each independently owned utility that files an application for transportation electrification investments must quantify how the investments further the EV-grid integration strategies in its application and report its progress in its load research report filing or alternative compliance filing with the CPUC.

6) The CPUC must review each LSE's annual measurable progress in furthering EV-grid integration strategies and issue recommendations to ensure progress.

This important piece of legislation has resulted in CPUC approval of three VGI pilot projects in PG&E service territory. A $7.5 million program was approved to enable 1,000 households with EVs to adopt bidirectional charging solutions for local reliability. A second pilot program is focusing on bidirectional charging at commercial sites, with 200 medium and heavy-duty vehicles, with a budget of $2.7 million. A third program, for $1.5 million, would focus on microgrid solutions that include bidirectional EVs for wildfire risk mitigation.[12]

SB 233 and SB 59: Bidirectional EV Charging

In January 2023, Senator Skinner introduced SB 233, along with co-authors Archuleta, Ashby, Becker, and Min in the Senate and Ting in the Assembly. The bill would have added Chapter 8.8 (commencing with Section 44269) to the California Health and Safety Code.

[12] https://www.utilitydive.com/news/california-approves-117m-vehicle-to-grid-pilots-in-pge-footprint/621393/

After being introduced the bill was amended several times in both the Senate and the Assembly. The initial version of the bill would have required all EVs sold in California to have bidirectional capability by 2030, but this provision was subsequently removed and language was inserted to "authorize the [California Air Resources Board (CARB)], in consultation with the California [Energy Resources Conservation and Development Commission] and the CPUC, to require any weight class of battery electric vehicle to be bidirectional capable if the determines there is a sufficiently compelling beneficial bidirectional-capable use case to the battery electric vehicle operator and electrical grid." Hence, the reference to any specific date was removed and the determination of a bidirectional requirement would be left up to CARB.

After failing to pass, SB 233 has now been superseded by SB 59 (also Skinner). This more general bill, enacted into law on September 5, 2024, requires any weight class of vehicle sold in the future to be bidirectional capable if "there is a sufficiently compelling beneficial bidirectional-capable use case to the battery electric vehicle operator and electrical grid." This determination is to be made jointly by the CEC, CARB, and CPUC.

SB 493: Air Pollution: Alternative Vehicles and Electric and Hydrogen Infrastructure

In February 2023, SB 493 was introduced by Senator Min with co-authors Newman and Rubio along with Alvarez and Davies in the Assembly. The bill addresses Sections 43024 and 43871 of the California Health and Safety Code. The bill would have required additional assessments of both hydrogen and electricity infrastructure for powering EVs including "the assessment of the electric vehicle charging infrastructure to additionally include electric system infrastructure and electric generation." The goal of the legislation was to identify key barriers and bottlenecks to providing EV charging and hydrogen fueling infrastructure in meeting state electrification goals. The bill was enrolled and presented to the Governor on September 20, 2023, but was then vetoed. The Governor cited funding constraints and potential duplication of efforts between agencies in returning the legislation without his signature.

SB 410: Powering Up Californians Act

In February 2023, SB 410 was introduced by Senator Becker as the Powering Up Californians Act. The bill addresses sections of the Public Utilities Code relating to electricity. The bill (now law) requires electrical corporations to assess staffing levels for adequacy and to identify the costs that they incur for delivering power to new customers as part of their general rate case proceedings. The bill cites delays that electricity customers are experiencing in developing or upgrading service for, among other things, "charging stations for light-duty, medium-duty, and heavy-duty vehicles." The bill requires improved procedures for customers to report energization delays to the CPUC along with other procedures designed to streamline progress for building and transportation electrification. The bill was enrolled on September 21, 2023, and signed into law on October 7, 2023.

Appendix B: Technical Requirements for Vehicle-Grid Integration

The concept of integrating EVs with the electrical grid depends on the flexible nature of EV charging and the ability of EVs to be connected to utility grids when it is most beneficial for grid operation and in circumstances that are conducive to grid support. This includes shifting loads from higher to lower demand periods, providing backup power, and providing other services to support grid operability such as maintaining 60 Hertz frequency. There are two critical technical dimensions to this: 1) physical grid connection issues including charging connector standards; and 2) communications protocols that enable EVs to leverage the flexible nature of charging to respond to grid conditions. Modern EVs with relatively large battery packs typically do not need to be charged every day, giving most drivers considerable flexibility in the timing of charging. Developments in both topics have evolved rapidly in recent years and continue to do so.

Charging Connector Standards

Electric vehicle charging connector standards define the physical and electrical requirements for connecting an EV to a charging station or an electrical outlet for the purpose of charging the vehicle's battery. These standards ensure compatibility and safety between different EV models and charging infrastructure. Understanding the various charging connector standards is crucial for EV owners, companies that operate networks of charging stations (also known as CPOs or charge point operators), and policymakers. The primary standards adopted in North America are summarized below.

Society of Automotive Engineers J1772 Charging Standard

The Society of Automotive Engineers (SAE) J1772 connector, also known as a J Plug or Type 1 connector, is a charging standard used primarily in North America. It features five pins and can charge up to 80 amps with 240-volt input, providing a maximum EV charger power output of 19.2 kW. The J1772 EV connector supports single-phase AC charging for Level 1 (120-volt) and Level 2 (240-volt) EV charging. The drawback of the Type 1 plug is that it only allows AC single-phase (versus AC three-phase) power and does not have an automatic locking mechanism like the Type 2 (Mennekes) connector used in Europe.[13]

[13] https://www.power-sonic.com/blog/ev-charging-connector-t

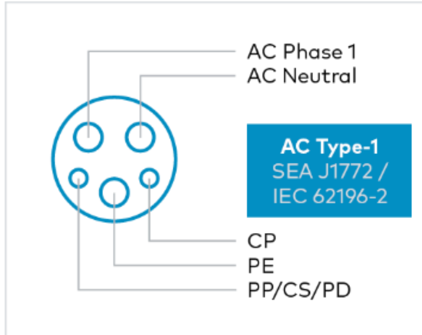

Figure 14. Illustration of the J1772 Connector

As of late 2023, almost every battery electric vehicle (BEV) and plug-in hybrid vehicle (PHEV) sold in North America has the J1772 connector except for Tesla vehicles that feature the NACS connector. Currently, Tesla provides a compatible adapter for free, allowing Tesla drivers to use a J1772 charger when needed.

A few major automakers, including Ford, General Motors, and Rivian, have recently announced that they will equip future vehicles with NACS charging inlets. See the below section for more details regarding the NACS connector.

Combined Charging System (CCS)

A Combined Charging System (CCS) Type 1 (or CCS Combo 1 or SAE J1772 Combo connector), combines the J1772 Type 1 plug with two high-speed direct current (DC) fast charging pins. CCS Type 1 is the DC fast charging standard for North America. It can deliver up to 500A and 1000V DC, providing a maximum power output of 360 kW.

The CCS utilizes the same communication protocol as the SAE J1772 Type 1 connector. It enables vehicle manufacturers to have one AC and DC charging port rather than two separate ports.

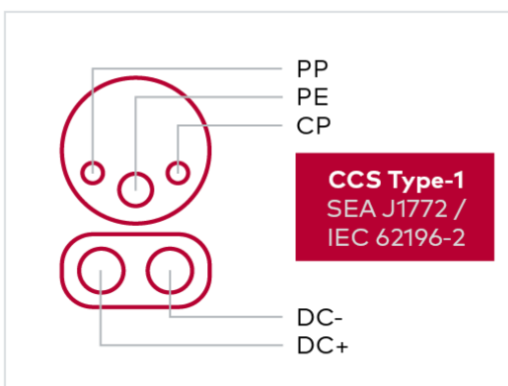

Figure 15. Illustration of the CCS Type 1 Connector

Most EVs in North America now utilize a CCS Type 1 plug for DC fast charging. Japanese automakers such as Nissan have transitioned from CHAdeMO to CCS Type 1 for all new models in North America. However, like the SAE J1772 Type 1 plug, Tesla has their proprietary charging standard for NACS.

Megawatt Charging System (MCS)

The Megawatt Charging System (MCS) is a DC fast charging connector currently under development by CharIN and dating back to 2018. Based on CCS, its mission is to provide a common solution for high-power charging to satisfy the market demand for heavy-duty and commercial EVs. According to CharIN's website, the MCS is designed for a maximum current of 3,000A (3 kA) at up to 1,250V (1.25 kV), which means a potential 3.75 MW of peak power.[14] After completing development and tests, including at the National Renewable Energy Laboratory in 2020, a working prototype of the MCS has been demonstrated on an Alpitronic charger and a Scania electric truck, which was able to receive more than one MW of power. According to ABB, a Swedish-Swiss EV charging infrastructure manufacturer, the first pilot project with MCS will be deployed in 2023, while the final commercial release is expected in 2024.

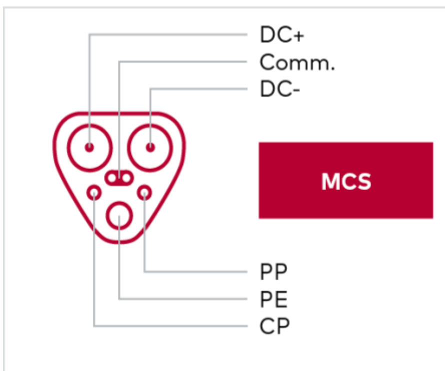

Figure 16. Illustration of the MCS Connector

To connect EVs to chargers, CharIN recommends a differential programmable logic controller (PLC) design, using the dedicated charging communication pins of the MCS connector. Since MCS is designed for a six-fold higher current and up to 10-fold higher power compared to CCS (which uses a "single-ended" PLC) without the dedicated connection pins MCS is not robust enough from "signal noise" for the expected increase in electromagnetic interference emissions.

This also reduces the necessity for signal level attenuation characterization (SLAC) used in CCS implementations, because differential signals produce much less crosstalk between adjacent charging systems. Therefore, CharIN suggests eliminating the SLAC protocol, which will reduce complexity and accelerate startup times.

For the communication protocol, MCS requires ISO 15118-20 exclusively as the market is moving toward more complex operations, such as secure handling of payment systems with "Plug & Charge" charging energy transactions, flexible charge management operations with fleets and large sites, V2G

[14] https://www.charin.global/technology/

power exporting, etc.[15] ISO 15118-20 is an international standard for communication between EVs and chargers, including enabling potential bidirectional power flows.

CHAdeMO Standard

The CHAdeMO connector is a DC fast-charging standard initially developed in 2010 by the CHAdeMO Association in Japan and released before CCS. The second-generation version can charge EVs at up to 400A, providing a maximum power output of 400kW. As of the preparation of this report, CHAdeMO remains popular in Japan, but is being equipped on very few new cars sold in North America or Europe. Although not as universal or widespread as CCS, there is still ongoing development with the CHAdeMO protocol to enable even faster charging through their "ChaoJi" technology, in partnership with the Guobiao or "GB/T" communication protocol. ChaoJi-1 is harmonized with CHAdeMO 3.1 (the latest version) in DC charging standards adopted in China in 2023, the largest global market for EVs.[16]

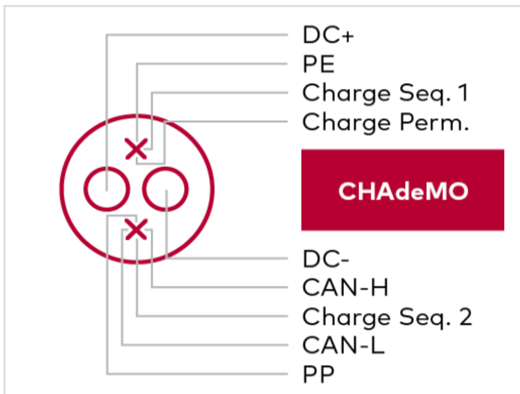

Figure 17. Illustration of the CHAdeMO Connector

The main difference between CCS and CHAdeMO is that CCS connectors allow car makers to supply one EV charging port, which can accept both AC and DC charging while CHAdeMO requires two separate charging ports for AC and DC. On the other hand, the CHAdeMO standard was designed to accommodate bidirectional power flows from its inception, which is unique since the other standards are still working to support bidirectional charging.

SAE J3068 AC Charging Standard

SAE J3068 defines both connectors and a communications protocol; like J1772 it is tailored for AC charging, but with more capabilities than any prior AC standard. The connectors are harmonized with SAE J1772, NACS/J3400, and European Type 2 connectors. The communications physical layer is LIN-CP with a robust set of signals that accomplish single- and three-phase charging, ability to load electrical requirements from charging station (or utility) onto the EV bidirectional charger, plug & charge, and capability to switch among simple charging, demand response, bidirectional charging, and

[15] https://www.charin.global/media/pages/technology/knowledge-base/c708ba3361-1670238823/whitepaper_megawatt_charging_system_1
[16] https://www.chademo.com/chaoji-gbt-standards-released

backup power. It also can be used for handshake and ID of station and EV to each other, then can switch to other control sources, such as automobile telematics, site Wi-Fi, or IEC15118. Several other standards, including J3027, SAE J3400, UL 1741-SC, and IEC15118 either allow use of LIN-CP with this signal semantics, or define transfer among their requirements and LIN-CP.

Because SAE J3068 is the only US standard to define an "EV Outlet", and includes multiple ways to lower cost and maintenance needs for AC charging stations, it appears to represent the most likely solution to the problem of urban charging such as curbside public chargers (Kempton et al., 2024).

North American Charging Standard (NACS) / SAE J3400

The North American Charging Standard (NACS), previously known as the Tesla charging connector, is an EV charging connector system developed and owned by Tesla, Inc.[17] It has been used on all North American market Tesla vehicles since 2012, and the communication protocol was opened for use to other manufacturers on November 11, 2022.

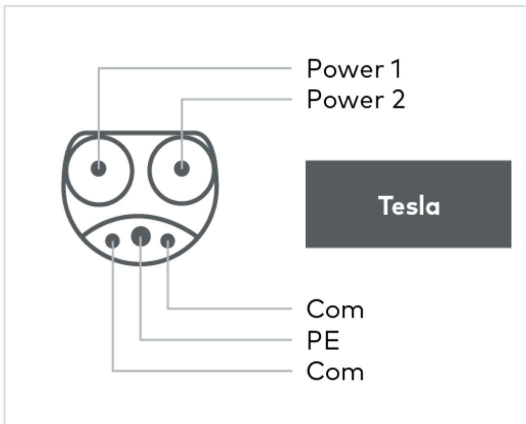

Figure 18. Illustration of the NACS Connector

Under AC power, the NACS connector can deliver up to 48A of current at 240V. Under DC power, there is both a 500V rated configuration and a 1,000V rated configuration, which Tesla claims is mechanically capable for megawatt charge levels. The 1,000V version is mechanically backwards compatible. While Tesla claims that it has successfully operated NACS above 900A continuously with a non-liquid cooled vehicle inlet, the maximum instantaneous current, which is a function of the ambient temperature and vehicle inlet capabilities, is rated at only 400A.[18]

According to Tesla, NACS is the most common charging standard in North America: NACS vehicles outnumber CCS two-to-one, and Tesla's Supercharging network, with more than 12,000 stations in more than 2,000 locations, has 60 percent more NACS locations than all the CCS-equipped networks combined. Although the majority of EVs sold in North America are compatible with NACS, most models are only compatible with CCS Type 1. Despite using the term "standard" in its name, NACS has not yet been recognized by any international standards development organization.

[17] https://www.tesla.com/blog/opening-north-american-charging-standard

[18] https://www.tesla.com/support/charging-product-guides#NACS-re

As of June 2023, Tesla is testing a proprietary dual connector called “magic dock” at a select ten North American Supercharger locations starting in March 2023 under the non-Tesla supercharger pilot program, which provides compatibility for both NACS and CCS Type 1 equipped vehicles. The United States federal government has confirmed that Tesla’s Supercharging stations will be eligible for federal subsidies as long as the chargers include a "standard connection"—in this case referring to CCS Type 1.[19] It is expected that Tesla will outfit many U.S. Supercharger stations with both connector standards, in part to gain access to several billion dollars of infrastructure build-out subsidies.

In May 2023, the Ford Motor Company announced it would integrate NACS into their EVs and permit drivers to pay for charging at Superchargers using the FordPass app. Starting in 2025, new Ford electric vehicles will have native NACS charge ports and older electric Ford models will be able to connect to NACS chargers with a NACS to CCS Type 1 adapter.[20]

In June 2023, both General Motors and Rivian announced that they would equip all new EVs with NACS charge ports starting in 2025.[21,22] Additionally, several EV charging companies also recently announced plans to adopt the NACS connector by offering adaptors or as part of future product offerings.

On June 27th, 2023, SAE International announced that it will standardize the Tesla-developed NACS connector. This will ensure that any supplier or manufacturer will be able to use, manufacture, or deploy the NACS connector at charging stations across North America.[23] The NACS standardization will be one of their priorities, alongside cybersecurity for charging infrastructure and reliability of charging infrastructure. Later in July of 2023, SAE voted unanimously to form a task force to expedite its NACS standardization process, and it aims to publish its work by the end of 2023, about six months after the start of the standards process.

Also on June 27, 2023, Volvo Cars became the first European brand to enter into an agreement with Tesla to use the NACS connector in the United States.[24] The deal with Tesla will open the Tesla Supercharging Network to all existing Volvo BEVs starting in the first half of 2024 with the use of a provided NACS to CCS Type 1 adapter. Additionally, Volvo intends to include the Supercharging Network in its software system, enabling on-route charging planning with real-time information on charger availability as well as the ability to make payments through one single interface.

On July 7th, 2023, Mercedes-Benz announced that it will integrate the NACS connector into its electric vehicle line-up in North America starting in 2025, the first German automaker to do so. Before the switch will occur, Mercedes-Benz intends to offer NACS to CCS Type 1 adapters in 2024 to gain access to Tesla Supercharging stations across North America.[25]

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[19] https://insideevs.com/news/671473/us-ccs-tesla-superchargers-publ
[20] https://arstechnica.com/cars/2023/05/ford-evs-will-get-access-to-teslas-supercharger-network
[21] https://www.cnbc.com/2023/06/08/gm-tesla-partner-on-ev-charging-net
[22] https://www.reuters.com/business/autos-transportation/ev-maker-rivian-adopt-teslas-charging-standard-2023-06-20
[23] https://www.sae.org/news/press-room/2023/06/sae-international-announces-standard-for-nac
[24] https://www.media.volvocars.com/us/en-us/media/pressreleases/316416/electric-volvo-car-drivers-will-get-access-to-12000-tesla-superchargers-across-the-united-stat
[25] https://media.mercedes-benz.com/article/00f3592a-3026-4dbf-b779-d878

On July 19th, 2023, Nissan also announced the switch from CCS Type 1 connectors to NACS in the United States and Canada. From 2025, Nissan will begin offering an NACS port on the new Nissan Ariya and other future EV models sold in those markets.[26] For existing Ariya vehicles, which are currently equipped with a CCS Type 1 connector for DC fast charging, Nissan will make a NACS charging adapter available in 2024. This will enable customers to connect their vehicle's charging port to NACS plugs at compatible chargers. This announcement did not mention NACS adoption for the Nissan Leaf models, which is the other Nissan EV model currently on sale. The Nissan Leaf sold in North America is currently compatible with the CHAdeMO charging standard for DC charging, which is a being retired.

On July 26, 2023, seven BEV manufacturers—BMW Group, General Motors, Honda, Hyundai, Kia, Mercedes-Benz, and Stellantis—jointly announced that they will create a new fast-charging network in North America (under a new joint venture and without a name yet) that will operate at least 30,000 individual chargers.[27] The network will offer both CCS Type 1 and NACS connectors. The new network is expected to offer an elevated customer experience with amenities. The first stations will be launched in the United States in the summer of 2024.

Just a few weeks after the joint venture announcement, on August 18, 2023, the American Honda Motor Co. president and CEO confirmed in a round-table interview that the company and its luxury brand, Acura, will join the NACS coalition.[28] This move is driven by General Motors (GM)'s own adoption of the NACS and Honda's dependence on GM's EV platform in North America. Honda's next two mid-sized SUV EVs—the Honda Prologue and Acura ZDX—both will use the shared Ultium battery architecture from GM. The Acura ZDX launched first with the CCS Type 1 connector and Honda executive vice president Shinji Aoyama has stated that once GM switches to NACS, the Acura ZDX will follow suit, but this probably will not happen until 2025 or 2026.

For the up-to-date development and status on the adoption of the NACS (SAE J3400) connector by automakers, charging hardware manufacturers, and CPOs, EVStation has a comprehensive tracking page with the latest information.[29]

Society of Automotive Engineers J2954

SAE J2954 is an industry-wide specification for wireless power transfer (WPT) for light-duty EVs led by SAE International.[30] It defines three classes of charging speed, WPT 1, 2 and 3, at a maximum of 3.7 kW, 7.7 kW and 11 kW, respectively. This makes it comparable to medium speed wired charging standards like the common SAE J1772 connector protocol. SAE J2954/2 A will use a much more powerful WPT9 standard for 500 kW charging for medium and heavy-duty vehicles which have the room necessary to mount the larger induction plate.

[26] https://usa.nissannews.com/en-US/releases/nissan-to-adopt-north-american-charging-standard-nacs-for-ariya-and-future-ev-models?selectedTabId=rele

[27] https://media.mbusa.com/releases/seven-automakers-unite-to-create-a-leading-high-powered-charging-network-across-north-america

[28] https://electrek.co/2023/08/18/honda-confirms-adopt-tesla-nacs-driven-gm-adopt

[29] https://evstation.com/tesla-nacs-charger-adoption-tracker/

[30] https://saemobilus.sae.org/content/j2954_202208

In the near term, vehicles that can be charged wirelessly under SAE J2954 should also be able to be charged conductively by SAE J1772 plug-in chargers. SAE J2954 currently only addresses applications for unidirectional, stationary, and above-ground (surface mounted) installations. The latest revision was submitted to SAE International on August 26, 2022.

Electric Vehicle Charging Communication Standards

Electric vehicle charging communication standards define the protocols and messaging formats used for communication between an EV and the back end financial operations of a charging station. These standards enable the exchange of information related to charging parameters, certificate authentication, billing, and other essential data before and during the charging process. The following are the main charging communication standards related to VGI applications.

OCPP: Open Charge Point Protocol

The Open Charge Point Protocol (OCPP) is an open and standardized communication protocol designed for charging stations. It is developed to ensure interoperability and compatibility between different charging stations and charging network operators' central management system. Figure 19 depicts a basic schematic of the OCPP implementation.

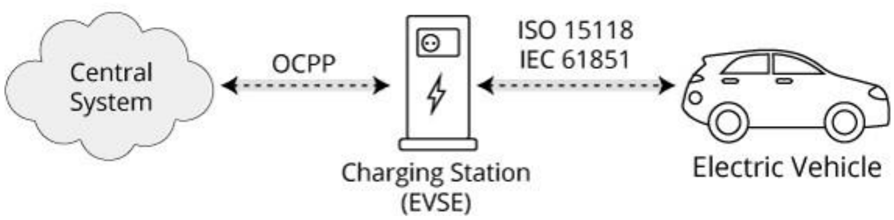

Figure 19. OCPP Communication Operation[31]

OCPP defines a standardized set of messages and protocols and enables features like remote monitoring, control, and management of charging infrastructure. It enables dynamic load management, billing integration, and network interoperability among OCPP-compliant chargers. Through the back-end network management software, hosts can monitor charger status, connect chargers to signals for local electricity pricing and demand response, and even set up a reservation system to allocate time slots to users. Through network interoperability and billing integration, EV drivers can use any charger in the network (regardless of who owns/operates it) with a single payment system.

However, with many of the grants from the U.S. Department of Energy (DOE) that allow network providers to choose their protocol, OCPP is not as highly adopted in North America among leading charging networks compared to other markets.

The first version of OCPP was developed and tested privately by ElaadNL in 2009. It is currently maintained and certified by the Open Charge Alliance (OCA). The latest version (OCPP 2.0.1) was published in March of 2020. OCPP 2.0.1 brings improved communication, interoperability, flexibility, and

[31] https://greenpowersystems.com/clean-transportation/commercial-evse/open-charge-point-protocol/

improved control/monitoring capabilities to CPOs seeking to scale and manage their EV charging infrastructure. Improvements have also been made in the areas of security, ISO 15118, smart charging and the extensibility of OCPP. A better explanation of the “device model” has been added as well as several other improvements. No major new functionality was added in this release.

According to the Federal Register website, the Bipartisan Infrastructure Law states that businesses must use OCPP 2.0.1-certified charging infrastructure to qualify for the National Electric Vehicle Infrastructure (NEVI) Formula Program.[32] The NEVI program offers incentives and subsidies to cover the costs of installing and operating charging stations.

The OCA website listed the following improved functionalities for OCPP 2.0 compared to the previous major release version OCPP 1.6:[33]

- Device management: Features to get and set configurations and to monitor a charging station. This is a long-awaited feature, especially welcomed by operators who manage complex multi-vendor, DC fast charging stations.
- Improved transaction handling: Especially welcomed by operators who manage large numbers of charging stations and transactions.
- Added security: The addition of firmware updates, security logging and event notification and profiles for authentication (key for client-side certificates) and secure communication.
- Added smart charging functionalities: A local controller for charging system topologies (physical system designs) with an existing Energy Management System, and additional metering and control systems for other types of facilities.
- Support for ISO 15118–2: Support for ISO 15118-2 regarding Plug & Charge and smart charging requirements from the EV.
- Display and messaging support: To provide the EV driver with information on the vehicle dashboard display, such as rates and tariffs.

OSCP: Open Smart Charging Protocol

The Open Smart Charging Protocol (OSCP) enables communication between building Energy Management Systems (EMS) or the local electric utility (also called a Distribution System Operator or DSO) and charging infrastructure regarding physical network capacity, including 24-hour forecasts of the available capacity of the electricity grid. Based on this forecast, service providers can generate charging profiles for EVs that make optimal use of available capacity without overburdening the grid. This is key for developing a smart grid ecosystem and various VGI applications.

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[32] https://www.federalregister.gov/documents/2022/06/22/2022-12704/national-electric-vehicle-infrastructure- formula-program

[33] https://www.openchargealliance.org/protocols/ocpp-201/

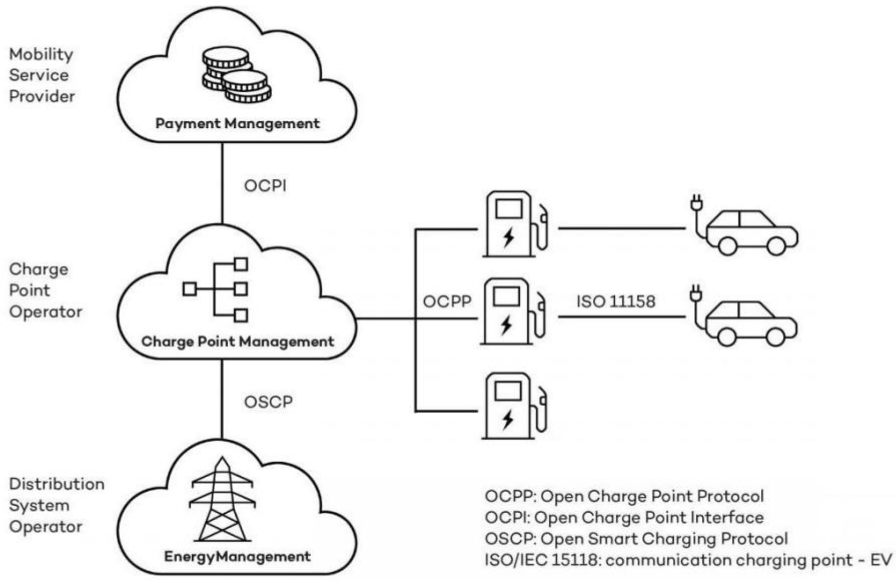

Figure 20. OSCP, OCPP, and ISO 15118 For Smart Charging[34]

OSCP has been developed based on the same openness and interoperability principles as OCPP. It describes the protocol for using flexible energy resources based on available capacity, primarily aimed at smart charging EVs by an electric utility/DSO.

OSCP 1.0 and its pilot implementations was released in May 2015, which defined the communication messages and forecast data for service providers to fit the charging profiles of the EVs within the boundaries of the available capacity of the electricity grid. The OCA adopted OSCP later that year, and it has been maintained by OCA since then. The OCA is a public-private consortium to promote open (non-proprietary) EV charging standards and protocols.

OSCP has been implemented in a challenging and successful field project at Dutch DSO Enexis. The project was executed in cooperation with charge service provider GreenFlux, Dutch public charge station operator EVNetNL and EV public charging knowledge center ElaadNL (both part of former Foundation e-Laad), IT solution providers and charge station vendors. OSCP facilitates capacity-based EV smart charging by standardizing the necessary information exchange (Portela et al, 2015).

OSCP 2.0 was officially released in October 2020. According to the official website, the new version permits messages to be exchanged among a broader group of users than with OSCP 1.0, which was specifically aimed at EV smart charging by a DSOs.[35] The reason for the change is that EVs are being integrated into larger energy ecosystems, including solar photovoltaics, stationary batteries, heat pumps and other devices. Other changes are the switch to JSON / REST for communication signals, additional types of forecasts (generation, consumption, fallback), and a message for reporting errors.

[34] https://afry.com/en/insight/electro-pop

[35] https://www.openchargealliance.org/protocols/oscp-20/

OVGIP: Open Vehicle Grid Integration Platform

The Open Vehicle-Grid Integration Platform (OVGIP) project was launched by U.S. automakers in anticipation of the spread of EVs to use their batteries as part of the smart grid to stabilize the system and alleviate congestion in power transmission and distribution lines. Since its inception in late 2012, OVGIP has been a joint utility industry and automotive industry initiative led by EPRI. The objective of the current Phase 2 OVGIP program is to advance the central automaker-utility interface concept and assess the effectiveness of the platform to integrate EV charging.

The OVGIP uses a central server to provide communications between the utility and the EVs. OVGIP establishes a common interface using utility industry communications standards and automotive vehicle telematics application programming interfaces (APIs). The OVGIP enables utilities to access data from the connected EVs including vehicle energy use, charging profiles, and consumer response to various signals or inducements intended to affect their charging behavior.

The communication platform architecture incorporates Open Automated Demand Response (OpenADR) signals generated by the utilities for EV load curtailment, that are then passed through to the vehicle telematics systems. OpenADR is designed to standardize and simplify DR in a non-proprietary interface. This type of system can also provide benefits to EV owners, by allowing them to take advantage of utility incentives, and to ratepayers through improved grid capacity utilization. DTE Energy and Xcel Energy are the two early utility adopters of the OVGIP.

In mid-2018, SCE launched the OVGIP residential DR project to manage customer EV charging loads in a residential environment.[36] The participants in the project included American Honda Motor Inc. with its Honda SmartCharge™ program for Fit EV customers, Sumitomo Electric Innovation, SCE, and EPRI under its OVGIP Phase 2 Program.

Over the five-month (May-October 2018) test and demonstration pilot period, two sources of data were collected and recorded from the five participating EVs to measure and verify customer performance and compliance with the program. The primary data used were customer household electricity meter readings accessed through the SCE Green Button system, which were used to measure the load change between the average electricity use over the prior 10 days and the actual day of the DR event. The second set of data was the recorded customer charging profiles associated with the DR events from Honda. According to the project summary report, the study validated the viability for DR aggregation of EV charging load utilizing automaker telematics, and the ability to collect and report individual customer charging profile data for purposes of verification. The data showed that electricity use could be reduced by 26.48 kWh over a one-hour charging duration.

Starting October 2021, Xcel Energy began its “Charging Perks" smart charging pilot program with the participation of up to 600 EV customers in Colorado using the OVGIP. As illustrated in Figure 21, Xcel Energy is working directly with BMW, Ford, General Motors, and Honda to test its charge curtailment program. The program goals are to optimize the operations of the electricity grid, and to improve the use of renewable energy generation.

[36] https://www.dret-ca.com/research-studies/dr-advocacy/open-vehicle-grid-integration-platform/

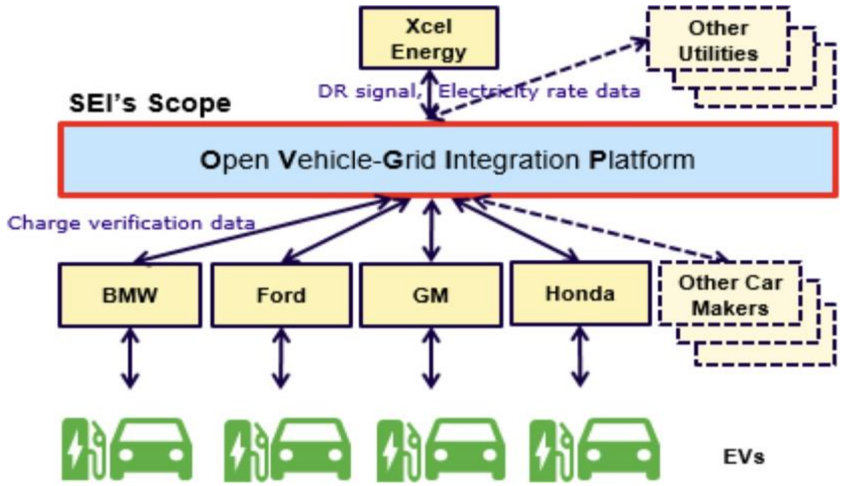

Figure 21. OVGIP Example System Configuration Piloted by Sumitomo Electric Industries, Ltd.[37]

ISO 15118: Road Vehicles – Vehicle-to-Grid Communication Interface

ISO 15118 is a globally recognized technical standard that relates to the communication protocol between EVs and chargers. It defines a comprehensive framework for bidirectional communication, ensuring efficient and secure interaction between the EV and the charging infrastructure. The communication parts of this protocol are the Electric Vehicle Communication Controller and the Supply Equipment Communication Controller. The standard also encompasses various aspects of EV charging, such as automatic authentication, authorization, and billing, using a combination of well-established communication technologies like Controller Area Network and Ethernet-based protocols.

ISO 15118 allows the EV and charging station to dynamically exchange information based on a charging schedule that can be negotiated and renegotiated. A charging schedule defines the timing, power levels, and energy prices for a charging event. These can be fixed in advance or varied in real time through one or more rounds of negotiation/renegotiation. Smart charging applications calculate an individual charging schedule for each EV using the information available about the state of the electrical grid, the energy demand of each EV, and the mobility needs of each driver (departure time and desired driving range). This way, each charging session can match the capacity of the grid to the energy and power demand of other simultaneously charging EVs. One of the distinctive features of ISO 15118 is the support for Plug & Charge (described below), allowing for seamless and automatic account authentication and payment authorization without requiring any further action by the purchaser. Moreover, the latest development standard facilitates V2G communication, enabling EVs to not only draw energy from the grid but also provide energy back to it during DR periods. Overall, ISO 15118 can play an important role in enhancing interoperability, cybersecurity, and smart charging capabilities within the rapidly evolving landscape of electric mobility.

The most recent version, ISO 15118-20, was published in April 2022, which extends the ISO 15118-2 standard released in 2014 and describes the requirements for the network protocol as well as the

[37] https://sumitomoelectric.com/press/2021/12/prs111

application protocol. The main changes are in the areas of energy transfer modes, the "physical layer" (circuits, wires, and plugs), and security. In addition to improving the functionalities covered by ISO 15118-2 (AC and DC charging, Plug & Charge, smart charging), new features include V2G/bidirectional power transfer, wireless power transfer, and automatic connecting device pantograph. In this version, wireless local area networks serve as the physical layer for wireless communication according to IEEE 802.11n. Moreover, ISO 15118-20 always requires Transport Layer Security (TLS) encryption with two-way authentication according to TLS 1.3 for charging communication, regardless of whether Plug & Charge is used. A group called Vector has developed a document that details the new features enabled with the latest development of the ISO 15118-20 Standard."[38]

Electric Vehicle Plug & Charge

Plug & Charge is a technological concept initially introduced and enabled by ISO 15118, implemented in proprietary form in Tesla's implementation of NACS, and standardized for AC charging in SAE J3068. It provides a more user-convenient and secure EV charging at certified charging stations that supports the standard. Currently, it applies to both wired (AC and DC charging) and wireless charging and allows for automatic and seamless authentication and authorization. All processes between compatible EVs and the charging station are carried out automatically and safely in the back end of the communication system. EV drivers need only connect the charging cable to their vehicle for a charge session to be initiated.

Plug & Charge deploys several cryptographic mechanisms to secure this communication and guarantee the confidentiality, integrity, and authenticity of all exchanged data. This prevents malicious third parties from intercepting and modifying messages and tampering with billing information between EVs and charging stations that are connected to the grid.

The secured communication is achieved with digital certificates under ISO 15118, which are data blocks that are electronically signed by a trusted Certificate Authority used to verify that a public key belongs to an authorized party. The certificates used to authenticate and authorize access are issued to EVs, charging stations, and the other market participants that are essential to the Plug & Charge process. The technology used in this process is called Public Key Infrastructure (PKI) and is based on asymmetric encryption.

There are several certificates needed for a Plug & Charge session: The automotive manufacturer produces the ISO 15118 compatible EVs and publishes the provisioning certificates for end-users (individuals or fleets) while maintaining the back-end data servers that manage the certificates authenticated by a PKI. The EVs must also have an ISO 15118-compliant V2G root certificate installed in the its communication controller to take advantage of V2G functionality. Similarly, the charging station that is connected to the CPO's back-end server must also have the V2G root certificate installed in its communication controller signed by the PKI to authenticate itself during the charging session. The EV owner can sign up for charging services/membership from a MO to create a billing account, with whom they share payment details to process the costs from a charging session. The MO

[38] https://www.vector.com/int/en/download/intelligent-charging-with-the-new-iso-15118-20-standard/

then stores the payment information and generates a digital contract certificate that is stored in the vehicle, which needs to be signed by the V2G root PKI to authenticate the identity of the EV owner during a charging session. In Europe, this PKI is provided and verified by Hubject (an e-commerce service). However, there is not yet a company or organization to provide these certificate services in the United States, which is currently a major obstacle to implementing Plug & Charge in ISO 15118.[39]

When the charging cable from a compatible charger is plugged into the EV, the station sends its set of digital certificates to the EV through ISO 15118, whereupon the EV can then authenticate the certificate and identify the trustworthy charging station to enable a secure communication channel with a TLS handshake. After the EV has presented its contract certificate to the charging station and is authorized by the driver's mobility operator, it can start charging its battery according to the charging schedule that was negotiated with the charging station. No external payment or identification (e.g., membership card, mobile app, credit, or debit card) is required.

The Plug & Charge ecosystem is growing as more EVs and chargers are being produced. According to Hubject,[40] the automakers and CPOs who currently support and implement the Plug & Charge feature in their EV lineups and chargers are:

- Automakers: Volkswagen, Audi, Ford, Porsche, Skoda, Lucid, Mercedes-Benz, Genesis, Hyundai, BMW.
- CPOs: Ionity, BP Pulse, Electrify America, BayWa, Shell Recharge, Ev Way.

IEEE 2030.5: Standard for Smart Energy Profile Application Protocol

IEEE 2030.5 is a standard for communications between the smart grid and consumers. The standard is built using Internet of Things (IoT) concepts and gives consumers a variety of means to manage their energy usage and generation. It defines a communication framework for interoperability between various smart grid devices and systems, enabling them to exchange information and manage energy resources efficiently. Information exchanged using the standard includes pricing, demand response, and energy usage, enabling the integration of devices such as smart thermostats, meters, PHEVs, smart inverters, and smart appliances. Figure 22 presents the overall set of functions enabled by IEEE 2030.5.

[39] Source: https://electrek.co/2023/07/12/sae-wants-to-certify-nacs-by-end-of-year-and-fix-plug-charge-too
[40] https://www.hubject.com/ecosystem-overview

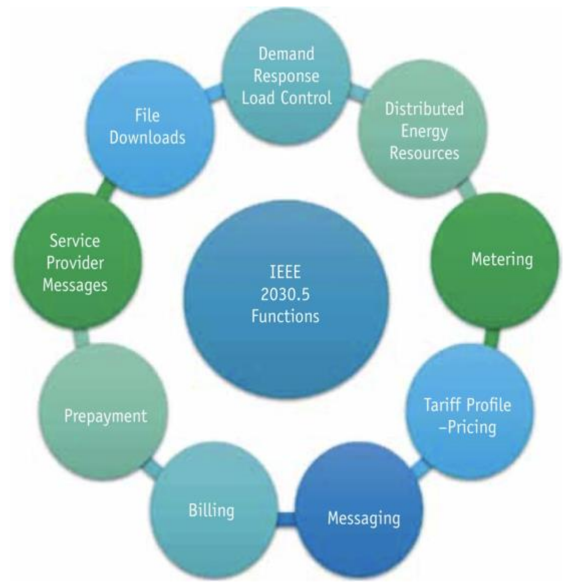

Figure 22. IEEE 2030.5 DER-related Functions
Source: IEEE

IEEE 2030.5 further defines a framework to support these applications to enable a secure, interoperable, and plug-and-play ecosystem of smart grid consumer devices. Particular emphasis is given to the integration of distributed energy resources (DER) with IOUs as IEEE 2030.5 has been adopted in California as the default communications protocol for residential DER integration applications (including V2G) for California's IOU Rule 21, and it is the first standard mandated anywhere for DER management.[41] Rule 21 is a long-standing interconnection standard that guides connection, operation, and metering for DERs, and also requires compliance with IEEE 1547 for safety.

Before the development of IEEE 2030.5, the former ZigBee Smart Energy version 1.0 (SEP 1.0) specification was ratified as a final specification by the ZigBee Alliance in December 2007. This was designed as a metering communication solution primarily to coordinate with behind-the-meter building energy devices. The initial application was focused on smart grid communications to residential appliances and other energy-consuming devices within a home network.

The standard was developed by many stakeholders across the energy supply ecosystem, including manufacturers of smart meters, appliances, programmable thermostats and other devices in homes, utilities, energy service providers, and various government and standards organizations around the world. Work on the standard (known at the time as SEP 2.0) started in 2008 and in 2009 it was selected by the United States National Institute of Standards and Technology (NIST) as a standard for home energy management devices. SEP 2.0 formally became an IEEE standard in 2013, adopted as IEEE 2030.5-2013.

Between the development of IEEE 2030.5-2013 and its adoption as an IEEE standard, HomePlug Powerline Alliance, the Wi-Fi Alliance and the ZigBee Alliance formed the Consortium for SEP 2.0

[41] https://cdn2.hubspot.net/hubfs/4533567/IEEE-2030-5-and-IEC-61850-comparison-082319.pdf

Interoperability (known as CSEP) to address some gaps in the IEEE 2030.5 specification to accommodate the integration of DERs and enable more sophisticated energy management to add full support for IEEE 1547 (IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces). IEEE updated the standard in 2018 as IEEE 2030.5-2018.

In the 2018 update, the IEEE 2030.5–Smart Energy Profile Working Group adopted the DER information model used in the IEEE 1547-2018 interconnection standard, the same DER models defined in IEC 61850. Using these common asset models makes interoperability—a problem with which the electric power industry has struggled—much more achievable. This rich semantic information model standard allows for message-based communications rather than old telemetry register-based communication, so no register mapping is required.

The IEEE 2030.5 standard also includes an accompanying certification process led by the SunSpec Alliance. The certification process includes Common Smart Inverter Profile (CSIP) testing for compliance with California Rule 21 specifications, and SunSpec has partnered with numerous global authorized test labs to provide independent third-party certification testing. Certification processes support the entire IEEE 2030.5 technology stack: utility server, cloud aggregator, smart inverter, and gateway products. Upon successful completion of the independent certification process, certified vendor products are provided with SunSpec's PKI certificate to enroll in the IEEE 2030.5 protocol.

Aligned with the shift to using the public internet for communications, IEEE 2030.5-2018 was developed using widely adopted internet standards that are familiar and proven. This includes most notably the transmission control protocol/internet protocol (TCP/IP) suite and the hypertext transfer protocol (HTTP). Similar with the Plug & Charge features enabled by ISO 15118, TLS is also used by IEEE 2030.5-2018 to provide a variety of cybersecurity functions, such as authentication, authorization, and confidentiality. When combined as in IEEE 2030.5-2018, TLS and HTTP make up the familiar HTTPS protocol used by virtually all secure web infrastructure today. Thus, IEEE 2030.5-2018 combines standards like TCP/IP, HTTP, and TLS 1.2 with industry-best practices and application semantics to provide multiple options for communications between DER smart energy systems and utility management. Specifically, the well-defined profile of standards in IEEE 2030.5-2018 enables management of the end-user energy environment. This includes demand response, load control, pricing, metering, and management of distributed generation, EVs, etc.

The standard also defines the mechanisms for exchanging application messages, the exact messages exchanged, including error messages, and the security features used to protect the application messages exchanged between non-utility systems and utility/grid management. The security features needed to protect these application messages are where the realm of cybersecurity and communications for DERs and utilities intersect. As such, IEEE 2030.5-2018 specifies a variety of requirements related to cybersecurity while maintaining usability such as a modern default cipher suite, access control recommendations, and certificates and associated keys for servers and clients.

Progress in implementing IEEE 2030.5 is being rapidly made in California and around the United States. DER management systems (that monitor and control the operation of distributed energy technologies), load aggregator groups, building energy management systems, microgrid control systems, and various other types of gateways and inverter controllers are all incorporating IEEE 2030.5 at this stage. A robust DER protocol test and certification program is now in place and operating.

VGI Applications of IEEE 2030.5

Historically, the balance between energy and capacity and proper power quality, including proper voltage and frequency, has been managed through bulk energy resources using market systems that benefit the grid and the grid service suppliers. DERs provide an opportunity to utilize distributed assets for these critical grid services, and IEEE 2030.5 was designed to support energy, capacity, and ancillary services. While multiple communication protocols are currently available, California mandates IEEE 2030.5 for DER applications.

When paired with a DC V2G charger with bidirectional inverters, EVs can from a utility perspective be considered a DER for V2G applications, allowing it to manage EV charging cycles to import power from the battery pack back to the grid. A power inverter converts DC power, such as from an EV battery or solar photovoltaic panel, to AC power. The utility DERMS communicate with the aggregators, charging system operators, or building energy management systems, which then communicates to the charging station and manages the charging and export applications.

Since it is designed to enable bidirectional power flows, the standard can enable drawing power from the EV's battery and execute the grid settings needed to operate as a grid DER. Once the DC V2G charger has the information it needs and is connected to a compatible EV, the communications between the charger and EV can use ISO 15118 or an alternative equivalent protocol.

Nuvve Holding Corp.'s GIVe™ (Grid Integrated Vehicle) V2G platform was certified compliant with the IEEE™ 2030.5 SunSpec's CSIP standard in August 2022 after a successful compliance test in July.[42] This enables Nuvve's platform to connect and communicate with the leading DERMS. Nuvve's platform aggregates EV batteries across multiple sites and fleets to form a virtual power plant. Utilities and other Load Serving Entities (LSEs) can now draw upon the excess stored electricity in Nuvve-managed EV batteries during periods of peak load. Fleet operators can also offset their fleet electrification costs through revenues from their electricity exports. Utilities and transmission system operators can maintain grid reliability as millions of EVs come online as distributed electricity storage resources and not just additional electrical loads.

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[42] https://www.prnewswire.com/news-releases/nuvve-vehicle-to-grid-tech-receives-ieee-certification-for-utility-scale-communications-301667244.html

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