# Vehicle-to-Grid

*State of the Technology, Markets, and Related Implementation*

**3002008935**

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# ABSTRACT

This public release document provides an overview of vehicle-to-grid (V2G) as a technology, recent V2G studies, and an investigation of the applicability of V2G-related approaches in the United States—including potential customer interest, interconnection requirements, market rules, market pricing, value of competing resources, and possible alternatives.

This project will focus on outlining the V2G, definitions, a literature review, a project review, and related concepts.

**Keywords**

Ancillary services

Plug-in electric vehicle

Smart charging

Regulation services

Two-way power flow

Vehicle-to-grid (V2G)

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# 1 BACKGROUND

The Electric Power Research Institute (EPRI) is a 501(c) (3) not-for-profit public interest research, development, and demonstration (RD&D) organization dedicated to environmentally competitive generation, delivery, and end use of electricity for the benefit of society. Since the inception of plug-in electric vehicles (PEVs), EPRI works with numerous automakers, IT developers, equipment manufacturers, standards organizations, utilities, academia, and cognizant state agencies in the research and development of electric vehicles and related technologies, including vehicle-grid integration (VGI), which includes both grid-to-vehicle and vehicle-to-grid (V2G). EPRI endeavors to provide an objective and neutral perspective and evaluation of technologies and seeks to develop collaborative solutions that provide the basis for open access and engagement among a multitude of viable stakeholders to achieve the comprehensive objectives and requirements for PEV technology development, implementation, and deployment.

Over the last decade, EPRI has managed RD&D programs in the arena of PEV technology evaluation and demonstration programs worth over $130M, spanning vehicle performance, battery charging, infrastructure, standards, and related technology. This has included multiple original equipment manufacturer (OEM) PEV demonstration and grid integration programs with Daimler, Eaton, Ford, General Motors, Fiat Chrysler Group, Odyne, VIA Motors funded by U.S. Department of Energy, California Energy Commission (CEC), South Coast Air Quality Management District, and California Air Resources Board as well as a global base of EPRI-member utility organizations.

At present, EPRI is involved in several CEC Electric Program Investment Charge (EPIC) funded programs related to developing and implementing VGI technology solutions, including V1G and V2G. EPRI, under CEC Program Opportunity Notice (PON) 14-310, is developing a V2G integrated communications / control system solution using open Society of Automotive Engineers International (SAE) and IEEE standards, and under CEC PON 15-311 is developing an open-source demand-side resource integration platform that encompasses integration of PEV smart charging and load management systems. EPRI is also involved, from its inception, in managing the development of the Open Vehicle Grid Integration Platform (OVGIP) with the OVGIP collaboration team consisting of multiple automakers (Ford, GM, Daimler, BMW, Toyota, and Honda) and multiple utilities, including all three California investor-owned utilities

(IOUs). EPRI has developed several technical reports[1,2,3,4] on the attributes and progress of the Open VGI Platform development strategy and accomplishments.[5]

It is anticipated that the prevalence of PEVs will continue to increase as will their energy demands on the electricity grid. Automotive OEMs have announced the launch of more than 30 new PEVs through the end of 2019. Many of these vehicles will be routinely charged in a residential, workplace, or commercial setting. For utilities, this potentially represents a challenge to both traditional load growth planning and load management. Furthermore, the capability of fully electric vehicles is evolving with greater affordability and improved performance, especially electric range.[6]

The automakers have brought PEVs to the market, and these vehicles are poised to represent a growing portion of the transportation market. These vehicles rely on electricity to power their batteries by connecting to the electric grid. Because these vehicles have substantial batteries (up to 90 kWh) and are parked for long durations (more than 20 hours/day), there are opportunities to use the charging and discharging of the battery to integrate with the electric grid and satisfy local power requirements in certain circumstances.

## Definition of Vehicle-to-Grid (V2G)

**Common Terms Used for Various Forms of Vehicle Charge/Discharge Modes**

- V2G: Vehicle as a grid-tied resource; using grid interactive inverter (focus of this report)
- V2L: vehicle-to-load; vehicle as a generator operating local loads
- V½G or V1G: vehicle as a variable load during charging; charging power consumption is modulated by external system
- V2H: vehicle-to-home; vehicle as a home generator
- V2V: vehicle-to-vehicle; vehicle used to charge another vehicle
- V2M: vehicle-to-microgrid; vehicle used to support a microgrid
- V2X: generally refers to power flow from the vehicle to some external load

Note that some ISO/IEC standards use the term *vehicle-to-grid* to refer to communications from the vehicle to external systems.

**Figure 1-1**
**Common Terms Used for Various Forms of Vehicle Charge/Discharge Modes**

[1] *Open Vehicle-Grid Integration Platform: Unified Approach to Grid/Vehicle Integration Definition of Use Case Requirements*. EPRI, Palo Alto, CA; 2015. 3002005994.

[2] *Open Vehicle-Grid Integration Platform Phase 1 Development Update*. EPRI, Palo Alto, CA: 2014. 3002004037.

[3] *Unified PEV to Smart Grid Integration Approach Within Automotive and Utility Industries*. EPRI, Palo Alto, CA: 2013. 3002000665.

[4] *Open Vehicle-Grid Integration Platform General Overview*. EPRI, Palo Alto, CA: 2016. 3002008705.

[5] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

[6] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

V2G is the ability to provide power from a plug-in electric vehicle back to the grid in addition to managing its power load from charging. V2G is different from controlled charging (often called *V1G*; see Figure 1-1) because power can flow in both directions to enable useful service even when the battery is charged. V2G also often includes participation in a wholesale energy market. A V2G vehicle may be able to provide reserves, generation control, ramping, and/or energy. This also requires the alignment of the objectives of the various V2G stakeholders (the electric vehicle owner, an electric charging station operator, and the facility at which the vehicle is charging) as well as the ability of the independent system operator (ISO) to recognize the individual electric vehicle or aggregated set of electric vehicles as grid resources.

## Justification for Vehicle-to-Grid

The main reason for implementing vehicle-to-grid is to collect and share revenue from grid services between the actors mentioned previously. Grid services are used to maintain system reliability and consist of a variety of different services, such as frequency response and spinning reserves, many of which are paid for. The ancillary service that ensures that sufficient resources are available with reaction times less than 5 seconds is typically referred to as *frequency regulation*. The demand for this grid service is constantly varying over time to mitigate grid imbalances. Changing conditions on the wholesale and distribution grid can result in an increase in the value of existing services and may require the development of new grid services—many of which can be monetized. In contrast, frequency response currently is not monetized; outside of ISO areas, payment for frequency responses varies. Renewable generation (for example, solar and wind) may increase the demand for frequency regulation and other services. Traditionally this need was met by generation on automatic generation control. Aggregated electric vehicles may provide similar services directly and may reserve existing grid capacity for other purposes.

The PEVs currently in the market do not have the capabilities to provide all of the V2G- related services. In addition, standards are in process that enable communication and control of reverse power flow. A series of research activities and resulting data are likely needed before automakers can commit to enabling this technology in their vehicles.

## Specific Purpose

This report outlines the V2G-related concepts and the current state of the market of V2G. The intent is to provide stakeholders with an overview of V2G; an understanding of the key components; a review of V2G-related work; a summary of V2G pilots; and technical, market, and other gaps with V2G. Once the viable opportunities are identified, automakers and other technology providers can then commit resources toward developing product for this market. It is not expected that new technology will be required—rather, a repackaging of existing technologies. The ultimate goal is to integrate PEVs as an economically viable distributed energy resource (DER) that supports grid reliability and is beneficial to both ratepayers and PEV customers.[7] This may or may not include V2G participating as a grid resource on the wholesale energy market.

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[7] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

# 2

# NECESSARY COMPONENTS OF V2G

This section outlines the necessary components of V2G and the general state of commercialization.

## Vehicles

There are no U.S.-spec light-duty production vehicles capable of V2G. In Japan, both Mitsubishi (1.5 kW) and Nissan (6 kW) offer DC power export from the vehicle using an external device connected to the DC charging port. The PEVs will also need the ability to check that the charging station electric vehicle supply equipment (EVSE) can handle reverse power flow as well as the ability to check the line voltage at the interconnection to allow the on-board inverter to correctly operate.

Status: unavailable (OEM vehicles); in process (other startup electric vehicle manufacturers and special purpose medium-/heavy-duty vehicles).

## Hardware

The necessary hardware for V2G consists of an on-board or off-board DC-to-AC inverter. There currently are no mass-produced on-board products that can export power via an AC charging port, but some are available in low volume from companies such as AC Propulsion. However, an off-board inverter is available on the U.S. market (UL-certified) in 15 kW and 30 kW versions.

Status: production (off-board DC-to-AC); under development (on-board DC-to-AC).

## Software

Control and integration software is required at a minimum for electric vehicles relative to the needs of the grid. In addition, embedded software may need to be developed for the electric vehicle charging station and the PEV.

Status: under development; proven in pilot.

## Communication

The grid must be able to share its needs with the electric car, and the electric car must be able to share its abilities (such as charge rate and energy available) in addition to its preferences (departure time, price) of its driver. Both the grid needs and vehicle capabilities vary over time of day (24 hours) as well as day of the week.

Status: under development; proven in pilot. Near-term communications abilities include the ability to manage peak power consumption of several EVSEs at a site, novel methods to manage charging at a site, and the development of an open standard for charge station management (Open Charge Point Protocol). In the longer term, work is being done on the use of the Smart

Energy Profile or OpenADR protocols to manage vehicle charging directly on the vehicle as well as the ability to roam across networks.[8]

### Measurement and Verification

In addition to measuring the amount of energy provided, there needs to be a function to verify that the electric vehicle varied its charge rate or was available to vary its charge rate, provide power back to the grid, and so on in addition to quantifying power and/or energy. This need is amplified if the electric vehicles are spread out over a certain geographic location rather than centralized at a fleet's charging location. Direct to vehicle communication and control adds the challenge of locating the vehicle geographically and mapping it to specific grid assets.

Status: under development; proven in pilot.

### Interconnection and Safety

Anything that provides energy to the electricity grid needs to file an interconnection agreement with the connecting utility. This presents a challenge for a mobile device such as a PEV. In addition, it is currently unknown whether the electric vehicle or its charging station—or both—will be required to have an interconnection agreement. Furthermore, utilities require interconnection equipment to be safe as certified by a third-party Nationally Recognized Test Laboratory (NRTL); the certifying body responsible for the car specification is SAE. SAE is not an NRTL, and the car companies self-certify to SAE standards and practices and, in the United States, to requirements set in the Federal Motor Vehicle Safety Standards (FMVSS).

Status: under development.

### Market/Aggregation

A market needs to exist in which buyers and sellers can meet and exchange services at a certain price. Although this exists for large customers in some regions of the United States, there is no market for individual electric vehicle drivers to contract with the local utility or ISO. For example, the New England ISO requires its participants in regulation to provide at least 1 MW.[9] Aggregation of electric vehicles is further complicated by the constraint of power level of the vehicle charger itself or the charging station, whichever is less. Many parts of the United States do not have markets for grid services.

Status: under development.

### Regulatory Issues

Several key issues are impacted by regulatory considerations in the V2G and other smart charging development:

- For the appropriate regulatory authorities: to define the primacy rules among different grid benefits.

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[8] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

[9] *VEIC: Electric Vehicles as Grid Resources*. Morse, Glitman. May 2014, p.18.

- For utilities: need to develop methods to capture and return to customers the value that VGI provides to their distribution infrastructure.[10]
- In restructured markets: competitive energy suppliers need to develop products and/or services for customers to participate.

Status: under development.

### V2G Standards

SAE governs the standards-making for vehicle hardware. In addition, because SAE's focus ends at the vehicle, other standards bodies are involved in the V2G ecosystem such as Underwriters Laboratory, the National Electric Code, and IEEE. Currently Underwriters Laboratory and similar NRTLs certify devices. The National Electric Code has jurisdiction over installation. SAE produces standards (however, there is no enforcement mechanism) for the vehicles. V2G touches all three areas.

The current development and implementation of VGI applicable standards is fragmented among various industry and standards groups endeavoring to address presumptive use cases and technology agendas. Two recent EPRI reports[11,12] provide a comprehensive update on the state of the PEV infrastructure standards. Various alliances and associations within the EVSE industry are attempting to achieve consensus on standard protocols for interoperability between EVSE network providers in order to achieve uniform EVSE customer access and interface. Standards organizations such as SAE, IEEE, National Electrical Manufacturers Association (NEMA), and IEC/ISO[13] are still in the process of developing and enhancing communication protocols, especially for wireless charging and AC as well as DC V2G technologies. SAE documents are generally released as either Technology Information Reports (TIRs) or Recommended Practice (RPs) and as such are not systemically vetted or universally adopted or implemented on any large scale. PEV infrastructure requirements, standards, and communications technologies are all still evolving. These considerations dictate the need for system flexibility and adaptability to address the progressive evolution of VGI value, requirements, technology, and standards.[14]

Prevailing VGI applicable standards are OpenADR2.0b, IEEE 2030.5 (SEP2), ISO/IEC 15118, SAE J2847/1, SAE J2847/3, and OCPP (v1.6), which individually address segments of a holistic VGI ecosystem. OpenADR2.0b and IEEE 2030.5—with demand response (DR) and DER functional communications features—are the only potential end-to-end (end device to utility or third-party provider back-end) Open VGI system solutions. ISO/IEC 15118 specifically provides for communications between the EVSE and the PEV, with the behind-the-PEV communications

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[10] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

[11] *Plug-In Electric Vehicle Infrastructure Technology Update*. EPRI, Palo Alto, CA: 2015. 3002005977.

[12] *National Electric Transportation Infrastructure Working Council (IWC): 2015 Annual Report*. EPRI, Palo Alto, CA: 2015. 3002005970.

[13] Day 2 Proceedings (See Niemninski and Halliwell segments) from EPRI Infrastructure Working Council Meeting, March 2016. http://www.epri.com/Documents/Infrastructure%20Working%20Council%20Meeting/Day%20Two-%20Infrastructure%20Working%20Council%20(IWC)%20Meeting%20Presentations.pdf.

[14] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

left to third-party providers (mostly proprietary). In the case of IEC/ISO 15118, therefore, the EVSE becomes the translation point between a proprietary and open protocol and is vulnerable to “man in the middle” type hacker attacks. This is the key reason that the National Institute of Standards and Technology (NIST) Smart Grid Interoperability Panel did not include IEC/ISO 15118 in its catalog of standards (both IEEE 2030.5 and OpenADR 2.0b are included). In addition, as currently written, IEC/ISO 15118-1 (AC charging) and 15118-2 (DC charging) are not currently designed to support reverse power flow (as in V2G) applications. SAE J2847/1, J2747/3, and J3072—which all rely on IEEE 2030.5—do support V2G applications.[15]

An effort is underway to enhance IEC/ISO 15118-1 and 15118-2 to include reverse power flow applications, but standards-making is a multiyear development, validation, and technology adoption/proliferation process to achieve scale. The expectation is that these standards will evolve and new standards will be required to adapt to new VGI technologies and business models. At this stage, interoperability of these standards is critical to link these important elements of the complete VGI ecosystem. There is also the need for interoperability with non-standard Application Programming Interfaces established by specific industries and companies to ensure that they still provide a uniform behavior through a common interface to their operational back-end systems. Interoperability is an absolute must for enabling an all-inclusive, sustainable VGI system.[16]

IEEE 2030.5 and OpenADR2.0b are the only standard protocols that define end-to-end communications between the utility or aggregator and the PEV and, in some cases, between utility or third-party to the EVSE—depending on the infrastructure owner’s energy management requirements. It should also be noted that the California Public Utilities Commission (CPUC) Smart Inverter Working Group selected IEEE 2030.5 as the recommended standard protocol for communications between utilities and the manufacturer's grid-tied smart inverters for managing DER: IEEE 2030.5 has established certifiable DER functional feature sets that can provide direct integration between utilities and DER inverter systems (including PEVs). In addition, these protocols are easily leveraged through the use of existing PEV communications data transfer technologies.[17]

SAE is actively working on a full suite of documents for PEVs related to DER:

- SAE J2836/1: Use cases for communication between plug-in electric vehicles and the utility grid
- SAE J2847/1: Communication between plug-in electric vehicles and the utility grid
- SAE J2836/3: Use cases for communication between plug-in electric vehicles and the utility grid for reverse power flow

[15] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

[16] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

[17] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

- SAE J2847/3: Communication between plug-in electric vehicles and the utility grid for reverse power flow
- SAE J2931/1: Digital communications for plug-in electric vehicles
- SAE J2931/4: Broadband power line communication (PLC) for plug-in electric vehicles
- SAE J3072: Interconnection requirements for onboard, utility-interactive inverter systems

Each industry is endeavoring to address the development of standards for interactive grid integration of its VGI-related products and services. Determination of appropriate standards requires implementation and verification of the individual industry-applied protocols against the requirements of the VGI use cases and qualification to execute each actor's responsibilities. Because of the dynamic nature of a unified communications network system and the complexity for integrating and synchronizing multiple stakeholder objectives and priorities, it is likely that no single standard will suffice, but rather the most effective set of interoperable standards.[18]

Status: under development; proven in pilot.

## Association

*Association* means pairing a specific PEV charging event from the grid with a specific utility billing/metering account. This is presently being required for some, but not all, utility DR programs and is not intended to be required for PEV aggregated DR programs.

Every DC charging-equipped PEV has PLC on-board for EVSE communications. SAE J2931-4 specifies the use of HomePlug GPHY PLC and includes the requirements and methodology for association, but it is protocol agnostic. ISO/IEC 15118-2 also stipulates the use of HomePlug GPHY PLC, which is the result of a harmonization effort for DC Fast Charge communications control between ISO/IEC and SAE.

Two issues should be acknowledged with regard to association:

1. The specific requirements and needs for PEV-to-meter association are not well defined or yet determined by the utilities.
2. The association via PLC implies a physical, conductive electrical connection between the EVSE and the EV. As the industry continues to introduce wireless charging, new means of association will need to be devised if required to incorporate wireless charging technologies. Wireless charging is governed by SAE J2954, which has just been released as a TIR. Note that current wireless standards being developed do not have provision for V2G operation—they are strictly for charging.

With regard to requirements and need for association, indications are that utilities are taking the approach to measure and verify DR at the premise (residential and commercial building) primary meter level without any requirement to identify the PEV or to measure it independently from the premise meter. Utilities are also indicating the establishment of incentive-based pay-for-

[18] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

performance DR programs based on compliance with notifications to not charge during specified periods of the day. Compliance verification will be provided by the vehicle telemetry.

The California ISO (CAISO) is developing guidelines and rules that will allow distributed energy resource providers (DERPs) to aggregate DER (including PEVs) as a biddable energy resource for ancillary and regulation services. The aggregator or DERP is responsible for determining the measurement and verification requirements for each sub-resource. These requirements are still being evaluated and may include the use of on-vehicle telemetry for verifying PEV aggregated capacity.

PG&E is developing a distribution-level aggregated energy capacity control program. PG&E intends to contract with OEMs to provide access to prescribed aggregated energy capacity within specified sub-load aggregation point (sub-LAP) for DR and other load management programs as part of their resource adequacy requirements. The OEM is responsible for direct control of the energy resources used to guarantee that the capacity threshold is met, which can include PEV V1G and/or V2G capability. Driver participation is measured based on the vehicle telemetry.

Ongoing PEV research efforts include the objective for determining each use case's related association requirements and further acknowledge the need to investigate wireless alternatives for association.[19]

Status: under development; proven in pilot.

### Other Challenges

- Protection issues (for example, fuse condition, post-fault short-circuit current, device interruption rating, nuisance tripping, fault detection, and reclose coordination) and voltage issues (for example, capacitor operation, voltage regulator operation, and line drop compensation).[20]
- Safety issues: comply with distribution utility anti-islanding scenarios.
- Technical grid challenges to be overcome, such as how to handle overcurrent protection, instantaneous reclosing, ferroresonance, reduction insulation, and transformer ground faults.
- NERC-imposed restrictions on storage and demand-side load for use in providing regulation.

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[19] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

[20] *Premises Energy Management: A MatLab Platform for Discrete Event Simulation*. EPRI, Palo Alto, CA: 2011. 1022642.

Table 2-1 summarizes the status of various V2G-related components.

**Table 2-1**
**Summary of Commercial Status of V2G Components**

| Component | Status |
|---|---|
| Vehicles | Only available in special purpose vehicles |
| Hardware | Off-board equipment available in special circumstances |
| Software | Proven in research pilots |
| Communications | Proven in research pilots |
| Metering and Verification | Proven in research pilots |
| Interconnection and Safety | Under development |
| Market Aggregation | Under development |
| Regulatory | Under development |
| V2G Standards | Under development |
| Association | Under development |

# 3
# TECHNICAL DESCRIPTION OF POTENTIAL BENEFITS OF V2G

The integrated energy network is the clean energy system of the future. It is already happening. It involves cleaner electricity generation, widespread electrification, and increasing consumer choice. V2G and related technologies can be part of the integrated energy network.

At a high level, PEVs can serve two functions for the grid as part of V2G:

- As a generator providing voltage independent of a grid
- As a grid-tied resource providing current

Following are some key terms regarding wholesale electricity generation and related markets. They are important when it comes to understanding technical issues as well as costs and benefits of V2G.

## Reliability Services

Reliability services consist of the following:[21]

- Reactive power/voltage control
- Short-circuit contribution
- Frequency support
  - Inertial response
  - Primary frequency response
  - Regulation
  - Load following/ramping
  - Spinning reserve
- Resource availability
  - Fuel availability
  - Equipment availability
- Black start

Reliability services are sometimes known as *ancillary services*. Ancillary services consist of frequency regulation services (help with grid stability by responding within 4 seconds for up to 1 hour, and often simply referred to as *regulation*), frequency response/inertial response, spinning/non-spinning reserves (restore grid balance within 10 minutes for up to 2 hours),

[21] *Contributions of Supply and Demand Resources to Required Power System Reliability Services.* EPRI, Palo Alto, CA: 2015. 3002006400.

flexible ramping, and black start.[22] Outside of the Electric Reliability Council of Texas (ERCOT), there is little payment for frequency response, and currently there is no payment for inertial response.

Regulation balances changing demand on the grid and consists of three main categories: regulation up, regulation down, and in the case of PJM, regulation energy. Regulation up and down are used to balance supply and demand of electricity. Regulation down decreases generation output; regulation up adds generation. Regulation energy management combines the regulation up/down signal and manages the state of charge to be roughly neutral on an hourly basis. Frequency regulation's response time is 4 seconds via automatic generation control. V2G potentially fits well with these requirements although further development of SAE standards may be necessary.

In addition, following are types of ancillary services that may be less suitably matched to PEVs/V2G for technical reasons.

Frequency response and inertial response are two related services, typically provided by generators synchronized to the power system. They ensure that frequency is maintained within desired bounds after a large generator trips offline and are typically not compensated right now. Inertia is naturally provided through the spinning mass of the synchronous systems and slows down the rate of change of frequency after a fault. Synthetic inertia from inverter-interfaced resources is being investigated but is not widely used. Primary frequency response is typically used to provide governor control on synchronous generators, where response is automatic when a large change in frequency is observed. In recent years, the provision of primary frequency response from other resources such as wind turbines has been investigated, and V2G may be able to provide similar services.

Spinning reserves are similar to frequency response in the requirement to provide automatic response; they are simply defined as the extra available generating capacity already connected to the grid. This is accomplished by simply increasing the power output of the currently connected generators. Spinning reserves are used to respond after large contingencies on the system. They typically have to respond within 10 minutes and maintain response. Spinning reserves frequently receive compensation. Spinning reserves are not used for dips in renewable generation.

Non-spinning reserves are similar to spinning reserves, but do not need to be synchronized to the grid. They must be able to interact with the grid within 30 minutes when called.

### Renewable Generation Integration

Renewable generation requires flexibility in managing the grid. In other words, renewable integration with the electric grid poses unique challenges since not only does output vary with time of day, but it cannot be perfectly forecasted, and the output varies depending on the weather and may vary from minute-to-minute, requiring balancing resources to manage this variation, with response times between a few minutes to several hours.

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[22] *Energy Storage Valuation Analysis: 2015, Objectives, Methodologies, Summary Results, and Research Directions*. EPRI, Palo Alto, CA: 2016. 3002006068.

The three potential responses are categorized as follows in order of increasing response time:

1. Regulation has a reaction time of seconds up to minutes.
2. Load following/shaping requires a reaction time of many minutes to hours.
3. Daily or hourly scheduling is the least time sensitive and is seen in terms of days.

There are also three related time specifications to consider: latency (how long it takes for the resource to respond to a request), lead time (how far prior does a resource need to respond) and response duration (how long a resource needs provide the service) as shown in Table 3-1.

**Table 3-1**
**Time Specifications to Consider in Potential Responses**

| | Latency | Lead Time | Duration |
|---|---|---|---|
| **Regulation** | Seconds | Seconds | Minutes |
| **Load Following** | Seconds | Seconds | Minutes to hours |
| **Daily** | Minutes | Hours | Hours |

Regulation, load following, and non-spinning reserves have been identified as potential sources of revenue in the next 10 years or so. Although all systems already have to manage load changes in the timeframes described previously, the variability and uncertainty associated with renewables are likely to increase the need for flexibility in all timesframes and may therefore increase the value of resources that provide such services. Because of the limited size of the electric vehicle battery, regulation and load following are the two services that a V2G-enabled electric vehicle may provide to support renewables integration on the grid.

It is important to note that lithium-ion batteries tend to lend themselves best to situations requiring a discharge time of minutes at a specific rate of power.[23] In addition, the impact on the battery of providing these services—and therefore the warranty—is currently unknown.

Lastly, ramping up/down is the speed at which the system load increases (or decreases) over time; this is typically increased with renewables. A steeper ramp rate is more problematic for the grid. Controlled charging or V1G may help decrease these ramp rates.

[23] http://www1.eere.energy.gov/solar/pdfs/50060.pdf, p. 4.

# 4

# SUMMARY OF RECENT V2G REPORTS ON STATE OF TECHNOLOGY, COSTS, AND BENEFITS

This section reviews some of the main literature on V2G pilots and related activities. Most of the pilots listed are focused on the wholesale market, but a few important distribution level pilots are also included.

### EPRI 3002008866, *Open VGI Platform, Systems Integration to Standards and Interoperability*

Focus: This technical report provides clarification on strategic direction of smart charging and interoperability standards necessary to maximize value to all stakeholders. Emphasizes interoperability among various communication technologies used by the automotive OEMs. The Open Vehicle-Grid Integration (VGI) Platform is initially focusing on four use cases, including two-way power flow.

Results: Working toward a diverse set of standard and non-standard application programming interfaces leads to greatest interoperability among utilities, technology stakeholders, and automotive OEMs. This leads to market scale.

### EPRI 3002005989, *PEV as Distributed Energy Resources: Technology Update*

Focus: Provides stakeholders with an overview of requirements of reverse power flow and state of market, including barriers to commercialization.

Results: Although technically feasible, numerous barriers to commercialization remain, for example, lack of market maturity, lack of national uniform market, and complexity of interconnection requirements resulting from mobility of electric vehicles. Automotive OEMs will need to see a market to act. Vehicles drivers will need to clearly see the benefits. Utilities must see the V2G-enabled vehicles as a least-cost solution or as providing services otherwise not attainable. These are some of the key reasons that there are currently no production light-duty vehicles that feature the ability to provide reverse power flow.

### EPRI 3002005994, *Open VGI Platform: Unified Approach to Grid/Vehicle Integration—Definition of Use Case Requirements*

Focus: Answers three research objectives:

1. Establish the diverse program requirements for charging management, demand response, and associated pricing tariffs
2. Establish the information from the electric vehicle that would help with utility reliability and capacity requirements
3. Establish the utility requirements that might impact the customer's preferences.[24]

[24] *Definition of Use Case Requirements*. EPRI, Palo Alto, CA: 2015. 3002005994.

The underlying assumption is ensuring that the driver's preferences, state of charge, and so on are communicated to and heeded by the charging resource. The goal is to aggregate electric vehicles from various automotive OEMs in a specific geographic area to maximize potential benefits.

Results: Established 10 use cases with critical utility and automotive requirements and identified common security and protocol standards. Use cases included automated utility electricity rate tariff processing, aggregated PEV demand response and critical peak pricing, interface with home energy management system or energy services interface, interface with a building energy management system, interface with EVSE network provider, real-time pricing signal event processing, optimizing load management (ISO/IEC 15118), vehicle roaming, EVSE network functionality, and metering and data exchange. Security guidelines and requirements.

### EPRI 1022643, *PEV Fleet Valuation*

Focus: Creates a tool that simulates a fleet of PEvs as a grid resource, specifically its energy schedule as a fleet. Helps clarify what data are needed to value grid services provided by electric vehicles. Includes the data collection and processing needed for grid services. Does not include any capital, maintenance, or grid impact costs for charging the fleet of electric vehicles.

Results: Even after prioritizing transportation, energy to provide grid services remained—including peak shaving, regulation, and load shifting. Value is a few hundred dollars per year, either positive or negative. Also concludes that larger batteries and higher power chargers tend to provide more value. Localized marginalized prices affect prices across ISOs. Increasing the charger rate from 3.3 kW to 6.6 k W doubles the revenue from energy but provides less than a 50% increase in revenue from regulation. Analyzed driving behaviors and created a fleet simulation model as well as an evaluation of fleet performance of PEVs. Consistency and grid potential are two factors that impact the financial value of V2G. Spinning reserve still offers a potential for income but at a lower price.

### EPRI 1022642, *Premises Energy Management: A MatLab Platform for Discrete Event Simulation*

Focus: Describes how automated management of an electric appliance (including electric vehicle charging) in a home would work and potentially bring value to the home owner via power system–scale services (for example, demand response and regulation). The project was conducted as part of a larger battery-to-grid project (ISO to EV).

Results: Programmable thermostats reduce costs by 18% (14.21 kWh and 2.84 kW) whereas appliance rescheduling leads to energy reduction of 41% (5.53 kW and 1.84 kW), a reduction that is increased with a stationary battery to 61% (8.27 kW and 2.76 kW). This potentially means that the homeowner could save money using a premises energy management system (PEMS), which would include controlled electric vehicle charging. Electric vehicles may compete in power system markets: peak power, spinning reserve, and peak shaving and potentially in regulation.[25] Research question posited about the impact on of electric vehicle batteries. Also easier and more reliable to communicate with charging stations rather than via aggregator.

### EPRI 3002006068, *Energy Storage Valuation Analysis: 2015—Objectives, Methodologies, Summary, Results, and Research Direction*

Focus: Outlines role, cost, and benefits of energy storage. Provides an update on the latest utility energy storage pilots. Includes a description of energy storage value analysis, defining and scoping benefits, and outlining key compatibilities between grid resource and the grid. Outlines uses of energy storage in the utility context. Lists grid services provided by energy storage. Outlines use cases. Quantifies value. Outlines gaps and possible next research steps. Also outlines EPRI's Energy Storage Valuation Tool and three use cases: transmission, distribution, and customer. Finally, the report addresses the rationale of renewables integration for energy storage.

Results: Models run led to cost-effective results in the distribution use case; not cost-effective for transmission and customer use cases. In addition, the report stated that the rationale of renewables integration as a justification for energy storage is highly dependent on the characteristics of the specific site.

### CPUC/LBNL: Interim Report on Phase 1 Results, 2015 California Demand Response Potential Study Charting California's Demand Response Future (April 2016)

Focus: Broader fast response demand response in California, not simply V2G. Sizes the potential benefits and costs for the three California investor-owned utilities from the cost perspective of an aggregator in the day-ahead market. Key assumption: steeper ramps up and down as well as increased capacity later in the day (about 6 p.m.). Demand response will help meet California's resource capacity requirements. Enabling technologies include charging interruption (both 120 V and 240 V) of electric vehicles; behind-the-meter batteries; direct load control (DLC) air conditioning; programmable communicating thermostats and air conditioning; pool pumps with DLC; heating, ventilation, and air conditioning (HVAC) systems with auto-DR, DLC, or PCT; controlled lighting, refrigerated warehouses with auto DR; automatic and manual industrial load shedding; manual and automatic pumping control; data centers with manual DR; and wastewater treatment facilities with automated and manual DR.

Results: Using a 40 GW net load peak, DR could meet 15% of required net load capacity (6 GW)—of that, 4 GW dispatchable on the supply side and 2 GW on the load side at a price of $200/kW-year. Also found that time-of-use (TOU) pricing is the "most cost-effective option."[26] The report concluded that battery storage and EV charging were the most expensive of the end-use DR options.

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[25] *Premises Energy Management: A MatLab Platform for Discrete Event Simulation*. EPRI, Palo Alto, CA: 2011. 1022642.

[26] Alstone, et al., *2015 California Demand Response Potential Study*. April 2016, p. 9.

## ISO New England's Internal Market Monitor, 2015 Annual Report (May 2016)

Focus: Annual overview of the ISO market of New England. Regulation clearing prices changed on March 31, 2015 to include a capacity price and a service clearing price. Prior to that date, regulation was a single clearing price.

Results: Regulation clearing prices ($/MWh) paid by ISO New England from 2011 to 2015 are shown in Table 4-1.[27]

**Table 4-1**
**Regulation Prices ($/MWh), 2011 to 2015**

| | Regulation Clearing Price | | | Regulation Service Clearing Price | | | Regulation Capacity Clearing Price | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Min | Ave | Max | Min | Ave | Max | Min | Ave | Max |
| 2011 | 0.00 | 7.16 | 95.00 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2012 | 0.00 | 6.75 | 70.33 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2013 | 0.00 | 11.68 | 692.08 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2014 | 0.00 | 19.04 | 1,407.43 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2015[a] | 2.86 | 18.27 | 381.13 | 0.00 | 0.30 | 10.00 | 2.44 | 25.26 | 1,172.47 |

(a) Pricing rules changed on 3/31/15.

## Vermont Energy Investment Corporation: Electric Vehicles as Grid Resources in ISO-NE and Vermont (May 2014)

Focus: Examines how PEVs might be grid resources for the electric grid, starting with managed charging and moving to wholesale grid resources by providing ancillary services, and ultimately as fully integrated grid resources that enable the integration of renewable generation.

Results: The stakeholder community needs to focus in the short term on key issues to enable progress toward widespread vehicle-grid integration. These issues were identified as electric vehicle rates, stakeholder coordination, standards development, cost-benefit analysis, and V2G demonstration projects. Every 5 minutes, economic dispatch occurs in the New England ISO, helping balance the grid. This frequency (of time) leads to a small market with less need for regulation. New England ISO also does not require the bids to provide the same amount of regulation up and regulation down— a range is acceptable.

[27] ISO-NE 2015 Annual Markets Report, p. 155.

# 5
# V2G CASE STUDY OVERVIEW

## Department of Defense, U.S. Air Force Base, California

Background: The DoD used 42 electric vehicles with 15 kW capability on a military base in California. ISO: CAISO. Participated in frequency regulation selling power services at a 4 second time interval. Focused on capacity-based services: spinning and non-spinning reserves and frequency regulation (regulation up and regulation down) as well as peak power shaving. Used 2011 ISO values. The project ran Q1 2012 through Q1 2014.

Key results: Obtained agreement from CAISO, Federal Energy Regulatory Commission (FERC), the distribution utility (Southern California Edison), and the California Public Utilities Commission to directly bid into CAISO market. Regulatory and technical issues were the biggest challenges—for example, being a simultaneous retail electricity customer and wholesale participant as well as meeting CAISO requirements: minimum bids of 10 kW, 100 kW always online, and 500 kW of continuous charging/ capability for a full hour. Modeled benefits of $150 to $210/month. Charging stations cost is proportional to output. Challenges included unknown long-term viability of frequency regulation market as well as organization of how a fleet uses its vehicles. In addition, if the ancillary services market becomes saturated, V2G would need to find other markets to earn money.[28, 29, 30] In general, these markets are very small in the overall picture. With existing resources and with many other distributed energy resources also coming online, there may not be a large market for such services—so prices can be very low.

The DOD V2G pilot has highlighted some key results and issues for V2G:

- "CAISO would be able to support only 10–15 thousand PEVs with no other market participants, if vehicles are hoping to make $100 per month."[31]
- "The most CAISO regulation up and regulation down market income a PEV with 15 kW bidirectional V2G capability can expect lies between $102 and $122 per month, depending on the vehicle's availability, state of charge, and precision of CDS execution. ***These numbers do not consider the costs of bidding into the markets***."[32]
- "Available V2G charging power capacity constitutes the most important factor determining income from ancillary services markets. This makes fast charging (for example, fast DC charging) -discharging capability highly desirable. Nonetheless, given its high cost, clearly a

[28] http://cleantechnica.com/2014/11/24/keystone-schmeystone-part-ii-air-force-nails-biggest-v2g-fleet-world/.

[29] https://building-microgrid.lbl.gov/sites/all/files/lbnl-6154e.pdf.

[30] http://www.etcc-ca.com/summits/2012/conference/Demand%20Response%20Track/DR%20Session%205%20-%20Efficiency,%20Mobile%20Loads,%20and%20Consumer%20Preference-%20How%20do%20These%20Affect%20DR/DR5%20-%20Gorgonpuir%20-%20Department%20of%20Defense%20Perspectives%20on%20Vehicle-to-Grid.pdf.

[31] https://building-microgrid.lbl.gov/sites/all/files/lbnl-6154e.pdf, p. 13.

[32] https://building-microgrid.lbl.gov/sites/all/files/lbnl-6154e.pdf, p. 13.

trade-off must be made, especially since fast charging might also require infrastructure upgrade."[33]

### BMW/University of Delaware/NRG/PJM

Focus: Been working on V2G since 2007. Fifteen electric vehicles, February through May 2013. ISO: PJM. Participated in frequency regulation selling power services. BMW's Mini-E provides grid services by discharging battery after receiving signal from PJM.

Results: BMW Mini-E earns ~$100/month for providing regulation services. In Delaware, the main issue was political. PJM and the State of Delaware had to coordinate on market rules and a state law in order to allow V2G to occur there. PJM also lowered minimum connection to 100 kW.[34, 35, 36]

### BMW/PG&E Distribution

Focus: Distribution-level demand response program using 100 BMW i3s allowing for load reduction on high demand days coupled with energy storage from second-use batteries from BMW Mini-E. BMW i3 drivers receive upfront payment for participation and incremental payment per occurrence. No connection to CAISO/wholesale market.

Results: The program works effectively. High driver satisfaction.[37]

### INEES, Germany

Focus: Volkswagen, Lichtblick, SMA Technologies, and Frauenhofer Institute partnered to test V2G and model its economic prospects in Germany.

Results: V2G is technically feasible to provide capacity to the grid, but it is not economically viable at this time.[38, 39]

### NRG EVgo/UC San Diego

Focus: Building on the work done by University of Delaware and NRG as well as the DoD work at the Los Angeles Air Force Base, NRG EVgo will operate a fleet of nine custom Nissan and Honda electric vehicles capable of bidirectional charging. This fleet connects to the microgrid on the campus of UC San Diego. It is important to note that because UC San Diego is state-owned property, it is self-regulated. One research question is where to put the AC-DC inverter: on the

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[33] https://building-microgrid.lbl.gov/sites/all/files/lbnl-6154e.pdf, p. 13.

[34] http://www1.udel.edu/udaily/2013/may/vehicles-grid-050213.html.

[35] https://learn.pjm.com/energy-innovations/plug-in-electric.aspx.

[36] https://chargedevs.com/newswire/university-delaware-to-offer-bmw-mini-e-evs-for-lease-in-v2g-project/.

[37] https://chargedevs.com/newswire/pge-and-bmw-team-up-to-test-v2g-services/.

[38] https://www.lichtblick.de/medien/news/2016/06/15/intelligente-einbindung-elektrofahrzeuge-mindern-netzschwankungen.

[39] https://lbsflibraries.blob.core.windows.net/sflibs/docs/default-source/schwarminnovationen/inees_abschlussbericht.pdf.

car (Honda) or on the charging station (Nissan). The other two areas of research focus are helping to define the UL-type standards for inverters and developing energy storage use cases.

Results: In process.[40, 41]

### UCLA WinSmartEV

Focus: The project's goal is to balance PEV driver preferences with wholesale grid needs via centralized control, specifically focused on power sharing control and response time as well as voltage regulation, distribution, and energy storage—all subject to grid aggregated voltage constraints. Eighteen-month project.

Results: In process. Mitsubishi iMEV can provide 1.0 kW power back to local grid (Los Angeles Department of Water and Power).[42]

### V2G School Buses/Clinton Global Initiative/NRG

Focus: This project retrofits six diesel school buses with electric powertrain and places them in three locations in California. The buses are used during the school year as transport. The intent is to use the buses during summer months as grid resources. The buses have 70 kW bidirectional inverters, and charging infrastructure sites will have interconnection agreements with the local utility. The project estimates $6,100 per bus in annual V2G revenue, energy cost arbitrage, and peak demand reduction. Costs currently are unknown.

Results: In process. All six buses are planned to be delivered by June 2016.[43, 44]

### Massachusetts Vehicle-to-Grid Electric School Bus Pilot

Focus: The Vehicle-to-Grid Electric School Bus pilot will be one of the first demonstrations of electric school bus technology on the East Coast of the United States. The pilot is intended to demonstrate that electric drive technology can help reduce emissions in the transportation sector, which has traditionally been dependent on petroleum fuel, and demonstrate how school buses can provide electric storage for the grid.[45, 46]

Results: In process.

### Distribution System Aware Vehicle-to-Grid Services for Improved Grid Stability and Reliability/EPRI/Automotive OEMs

Focus: On this CEC-funded multiyear project, the focus is to equip on-vehicle V2G inverter-capable OEM PEVs (from Honda, Chrysler, and others) as well as EVSEs from AeroVironment (project partners) with secure SAE J3072 communications, interconnection, and grid-services-

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[40] http://www.energy.ca.gov/research/notices/2015-12-14_workshop/presentations/07__NRG__de_Leon.pdf.

[41] https://chargedevs.com/newswire/evgo-partners-with-uc-san-diego-on-vehicle-to-grid-projects/.

[42] http://smartgrid.ucla.edu/projects_evgrid.html.

[43] http://green-technology.org/gcsummit16/images/35-ZEV-School-Buses.pdf.

[44] https://chargedevs.com/newswire/california-program-to-demonstrate-electric-school-buses-with-v2g-technology.

[45] http://www.mass.gov/eea/pr-2016/electric-school-bus-grants-to-four-schools.html.

[46] https://www.veic.org/media-room/news/2015/12/01/electric-school-bus-pilot-project-launching-in-massachusetts.

related functions; connect them to the neighborhood transformer with power and temperature monitor; and manage their V2G power flow in response to simulated grid service requests that are constrained by transformer and distribution system capacity. The goal is to evaluate an end-to-end V2G capable system that is electrically safe, cyber secure, and part of a broader aggregated distribution system providing value-added services as well as to analyze the value created through these services in excess of simple unidirectional smart charging type applications to provide a framework for grid benefit calculations.

Results: This project is currently underway, expected to begin demonstration in 2017.

# 6
# V2G OUTLOOK

The bulk of the papers and pilot on V2G have focused on regulation services, which were outlined previously. As a refresher, regulation services help the grid operator balance short-term changes in the demand for electricity from the grid. This is achieved by adding or reducing power to the grid at that moment by grid resources. The nature of electric vehicle charging lends itself to groups of electric vehicles potentially serving as a regulation resource. That said, disagreement exists on whether plug-in electric vehicles will be a regulation resource and, if so, when.

## Current Arguments for V2G

Current arguments supporting V2G include the fact that a few Japanese automakers—notably Honda, Mitsubishi, and Nissan—are already conducting research and other tests on V2G. In addition, by buying the electric vehicle, the driver has already paid for a portion of the costs of the energy storage system necessary to participate in V2G—potentially reducing the incremental costs necessary for V2G. Some research has indicated that the value of bidirectional energy resources supplied via V2G is greater than that supplied by V1G. Finally, the necessary inverter technology has already been developed for other applications (for example, solar). This minimizes costs necessary to develop an automotive-grade inverter.

Further, certain special purpose vehicles might have more attractive opportunities for V2G. For example, school buses generally travel short and repetitive routes, which is ideal for battery electric drive technology. They also tend to sit idle for long periods of time, especially during the summer months, making them better candidates for vehicle to grid (V2G) and/or vehicle to building (V2B) technology than other vehicles that are used more regularly.

## Current Arguments Against V2G

Current arguments against V2G include having to overcome complicated regulatory and legal constructs; the unknown impact of the extra battery cycling on the life of the battery of the electric vehicle and any impact on warranty; lack of automaker interest; lack of consistent regional or national markets for V2G; lack of available production electric vehicles with bidirectional capability; consumers placing a higher value on driving than having their car serve as a grid resource; and outstanding technical issues such as where the inverter should be located. On-board inverters add weight, complexity, and cost to a PEV. Off-board inverters require an additional box containing power electronics and a user interface; however, an off-board inverter can help with safety and convenience issues by being integrated into a stationary device. There is also the question of timing. Because a car moves around, what happens when grid services are needed but the car is driving, plugged in at the wrong location, or plugged in but unable to provide grid services due to the state of charge of the vehicle or driver preference? Also to be considered are the costs of adding mobile inverters and bidirectional charging capabilities as well as going through full utility interconnection processes. There is also the question of timing of the need of demand for V2G versus the needs of the electric vehicle drivers. Because the need for wholesale products decreases over the course of the day (that is, there is more demand in the a.m.

hours and less in the p.m. hours), how does this match with the location of the electric vehicles, energy availed, and driver preferences—and how does this demand change as the amount of solar generation increases? Finally, there is the question of market saturation: once the technical, legal, regulatory, and market issues are resolved that allow for V2G, increasing the supply of V2G-type services against a foreseeable relatively fixed demand for the services may drive the market clearing price lower against relatively fixed costs, potentially making V2G unprofitable compared to other alternatives.

### Possible Alternatives to V2G

In addition to the current main alternative of conventional generation resources, there are three main alternatives to V2G on the customer side: stationary batteries, controlled vehicle charging (V1G), and management of non-vehicle loads.

Stationary battery packs are capable of supplying the same services as vehicles with V2G, but they have two additional advantages: they do not change locations like plug-in electric vehicles do, and they do not have another primary goal. In the case of electric vehicles, mobility is prioritized over serving as a grid service. Stationary batteries are likely to have higher capital costs than V2G because all components must be purchased, whereas V2G shares many components with the already purchased vehicle. However, widespread use of PEVs may also enable lower cost stationary storage through the use of refurbished "second-use" batteries. The demands of a PEV are generally more rigorous than those of the electric grid, so a battery in a PEV may reach the end of its functional life as an automotive battery but still have value as a grid battery. This may significantly reduce costs relative to new batteries, but because of the early stage of the PEV market, it is unknown at this point how much it would cost to remove, refurbish, and integrate a used battery pack to create a usable stationary battery.

Many of the benefits of V2G could be provided by controlled vehicle charging, or V1G. V1G avoids the cost of the DC-to-AC converter but can operate only until the vehicle battery is charged—and can only modulate demand rather than being able to draw and supply power.

Managing non-vehicle loads may provide benefits similar to those with V1G, although with a different mix of size and flexibility. The amount of existing non-vehicle load that could be managed, such as by thermostats, is much larger than the vehicle load will be for many years to come. Despite the size of this load, though, much of it will be less flexible than vehicle charging. For example, customers are unlikely to care exactly when their vehicle is charged—as long as it is ready when they need it—but they would not want to defer heating on a cold day.

### Distribution Issues and Potential Value

Another major question is the costs and benefits of managed charging on the distribution grid and how those compare to the costs and benefits of V2G on the wholesale grid. Although a limited wholesale market exists for large energy resources, there may be areas in which the PEV can provide value on the distribution grid. This would avoid the complexities of a distribution-level resource (or aggregated group of them) joining the wholesale market, but the benefits of managed charging on the distribution grid (for example, delayed infrastructure investment) and the costs of implementation need to be compared to the costs and benefits of V2G on the wholesale grid.

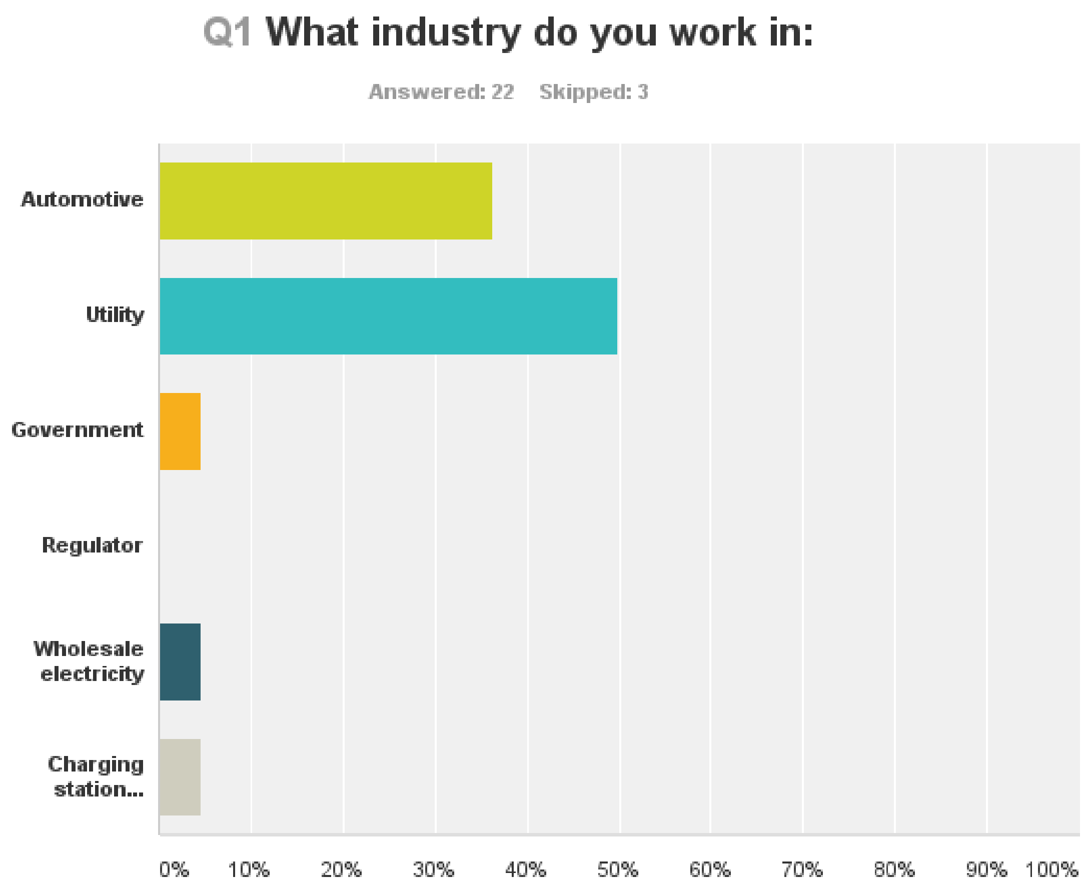
Possible value streams from a distribution perspective include peak shaving, providing distribution-level voltage regulation, helping address distribution grid issues caused by high penetration of rooftop solar, providing phase balancing, managing localized distribution constraints, and lowering facility upgrade requirements. These examples of distribution-level issues could also potentially be addressed by V1G, although with reduced flexibility.

# 7
# V2G STAKEHOLDER SURVEY

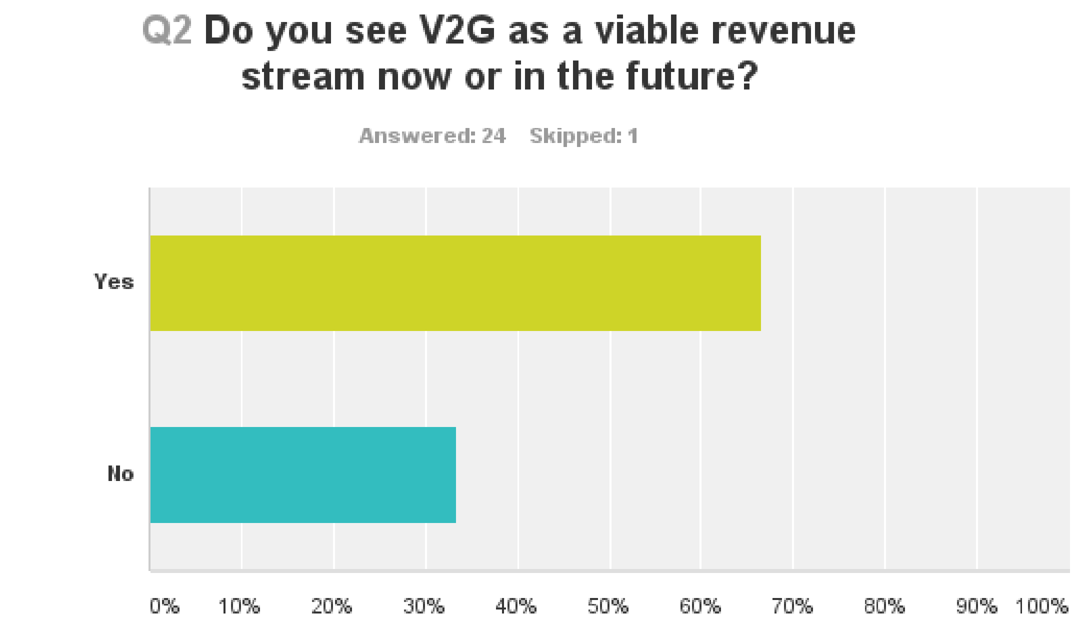
Thirty different stakeholders from the utility, automotive, technology, government, and electric vehicle community were surveyed to get a high-level view on the state of the market. This survey is not statistically significant, but it was performed to share an anonymous view of some of the leaders in the industry, each with a different viewpoint.

The survey questions were as follows:

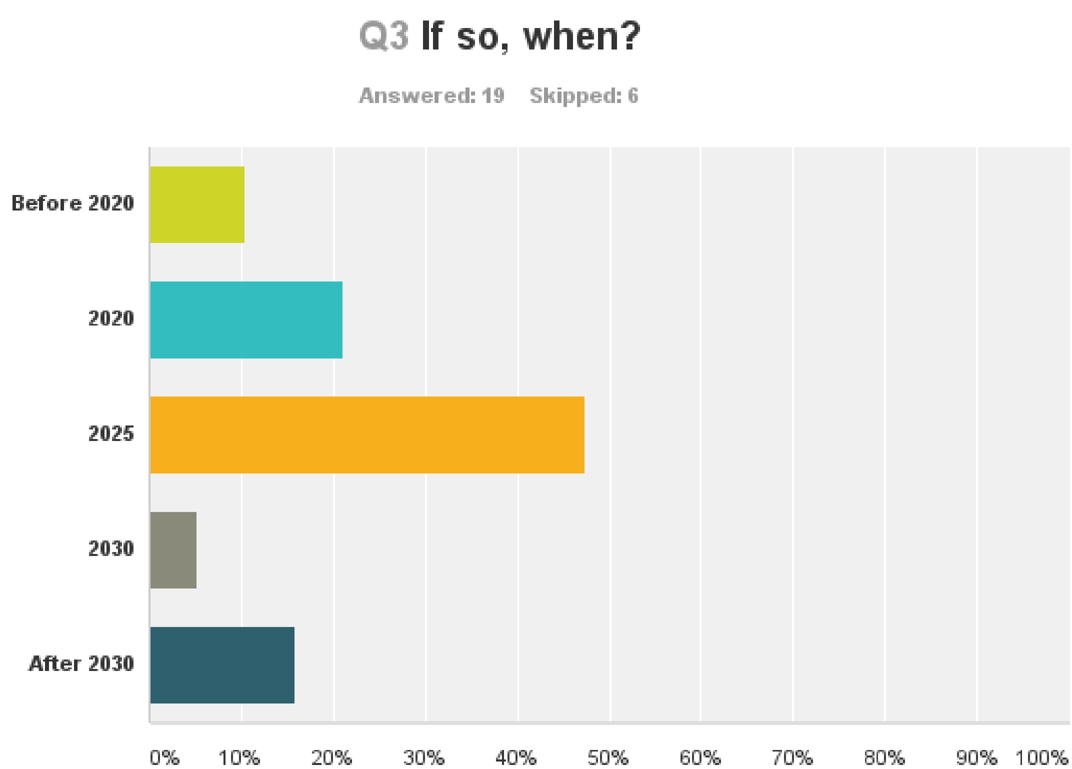
1. What industry do you work in (automotive, utility, government, regulator, wholesale electricity, charging station manufacturer, and so on)?



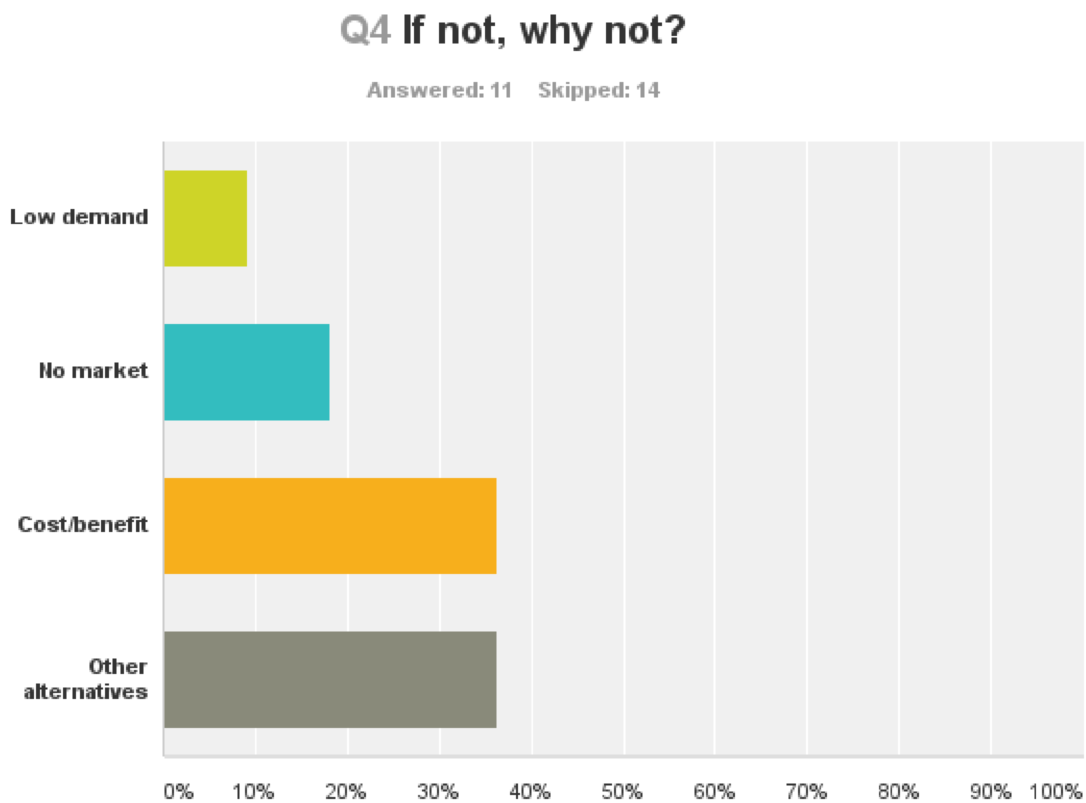
2. Do you see V2G as a viable revenue stream now or in the future?




3. If so, when? (Before 2020, 2020, 2025, 2030, after 2030?)



4. If not, why not? (Low demand, no market, cost/benefit, other alternatives, other?)




5. Anything else to add? (fill-in)
   - All of the above (low demand, no market, cost/benefit, other alternatives).
   - The complexities of the regulatory environment, grid operator/utility variations, and uncertain/complex business cases for fleets/consumers will drag out broad acceptance/application for many years—until/unless a real, pressing grid need arises. Until then, spotty and localized pilot programs.
   - Regulatory timing and program development/deployment.
   - V2G requires a product (automobile), form factor standard for interconnection, consumer demand, and battery technology.
   - The time needs to be right, the demand is not there, and the cost is high at the present time
   - V2B (vehicle-to-building) before V2G.

# 8 SUMMARY

Vehicle-to-grid, meaning using electric vehicle charging rates and energy to participate in the wholesale energy markets, has been researched and debated for more than a decade. Various pilots, largely in the Northeast and California, are attempting to gather performance data and actual cost and benefit figures to help inform future efforts. In parallel, technical and standards development continues.

A primary issue for development is the way in which PEVs may be a viable opportunity for being an individual and aggregated grid resource. The reality is that PEVs are being categorized as a potential distributed energy resource, requiring interface with diverse residential and commercial building energy management systems as well as energy service providers to serve as an integrated, controllable, mobile distributed energy storage resource. The solutions need to address the prioritization of the varied objectives among the PEV customers, the controlling infrastructure entities, the aggregators, and the energy service providers based on value for the grid and for the customer. The need exists to define the rules of primacy for the different grid benefits, as stated by the regulatory body, which are to address alignment of the fragmented objectives of the different actors involved in any particular charging arrangement. Further, a need exists to achieve a clear definition of the grid service use cases, the primacy rules, and the customer and utility value-based requirements to provide a path to qualify the standards and verify their capabilities to execute the necessary interactions among the relevant actors. In addition, the standards have been determined based on use case scenarios that may not reflect all of the requirements for a vehicle-to-grid integration structure in the future that shares its value with rate payers as well as PEV customers.[47]

The technical issues are not trivial. For grid services, V2G and any potential substitutes need to consider locational compatibility with grid services, technical computability with grid services, prioritization of reliability objectives, regulatory barriers or restrictions, market or system optimization procedures, and business model compatibility.[48]

In closing, a finding from the DoD V2G pilot at a U.S. Air Force base in California concludes: "The cost and complexity of the system required to participate in V2G suggest that developing a cost-effective system poses a major challenge."[49] V2G pilots are attempting to find the appropriate applications and approaches to this opportunity.

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[47] *Open VGI Platform, Systems Integration to Standards and Interoperability*. EPRI, Palo Alto, CA: 2016. 3002008866.

[48] *Energy Storage Valuation Analysis: 2015, Objectives, Methodologies, Summary Results, and Research Directions.* EPRI, Palo Alto, CA: 2016. 3002006068.

[49] https://building-microgrid.lbl.gov/sites/all/files/lbnl-6154e.pdf, p. 13.

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