Enhancing Grid Resilience with Integrated Storage from Electric Vehicles

Recommendations for the U.S. Department of Energy

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ELECTRICITY ADVISORY COMMITTEE

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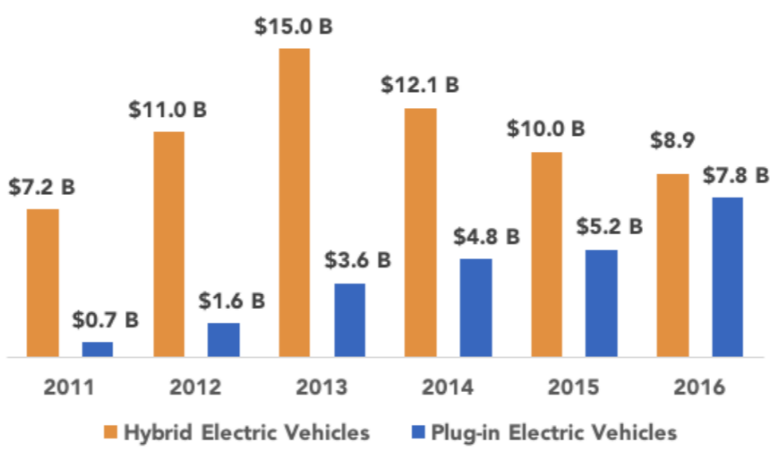
1 Introduction

Natural and man-made disasters threaten the electric grid's ability to deliver reliable, high-quality power. Routine voltage sags and momentary interruptions impact power quality and are costly to producers and consumers. As the U.S. economy becomes increasingly dependent on information and communication technologies, access to reliable high-quality electricity is needed to be competitive in the global marketplace.

A resilient grid can absorb shocks to prevent disruptions, manage disruptions as they occur, and return to normal operation quickly. As a result, the magnitude and duration of disruptive events is reduced. To be resilient, the grid must have the capability to (1) anticipate, (2) absorb, (3) adapt to and (4) rapidly recover from disrupting events (Appendix A).

The rising cost of grid disruptions underscores the need to identify cost-effective strategies and investments that can increase the resilience of the U.S. power system.[1] The emerging market of electric vehicles (EVs) presents a new opportunity to improve the grid. The plug-in EV market has grown from around 30,000 vehicles in 2011 to estimated 684,000 in 2016. This translates to a six-year compound annual growth rate (CAGR) in unit volume of 87%, and nearly $7.8 billion vehicle sales revenue in 2016.

Figure 1. U.S. Hybrid and Plug-in Electric Vehicle Revenue[2]



With the EV market on a steady foundation, automakers are beginning to develop offerings and technologies that will likely accelerate market acceptance. As a result, the load on the electric grid from EVs will grow so it is important to examine the potential impact on grid reliability and resiliency. The investments needed to integrate EVs into the electric grid could even potentially be leveraged as a means of strengthening the reliability and resilience of the grid. While EVs offer well-to-wheel greenhouse gas and local pollution reductions,[3] they may also be a key to enhancing grid security.

This work product examines the ability of integrated storage from EVs to enhance grid resilience. Three modes of EV integration are considered:

- Grid-to-Vehicle (G2V) - Smart and coordinated EV charging for dynamic balancing to make vehicle charging more efficient; it does not require the bi-directional flow of power between the grid and the vehicle.
- Vehicle-to-Building (V2B) – The discharging of electricity from EVs to building energy management systems, providing back-up and emergency services to homes and businesses; it requires a bi-directional flow of power between the vehicle and the grid and/or distributed energy resources and the ability to discharge power to the building.
- Vehicle-to-Grid (V2G) - EVs providing the grid with access to mobile energy storage for frequency and balancing of the local distribution system; it requires a bi-directional flow of power between the grid and the vehicle to enable provision of advanced grid services.

Each mode of EV integration comes with a unique set of grid resilience attributes and possibilities, and the need for these grid services will vary across states and regions. Current levels of reserve margins and shares of variable renewable energy will influence the potential revenue opportunities for EVs from reserve, voltage control and frequency regulation markets.

2 Approach

Our approach included a review of the literature, questionnaire responses from members of the Department of Energy's (DOE) Electricity Advisory Committee (EAC), discussions with experts in the field of EV grid integration,[4] and examination of information about relevant pilot projects.[5]

This work product examines how each of these modes of EV integration can provide cost-effective resilience services. Specifically, the scope covers:

- the technology readiness of EVs to contribute to grid reliability and resilience;
- the magnitude of the benefits that could be delivered;
- the business and ownership models that might be deployed including the role of intermediaries, aggregators, and coordinators;
- possible arrangements for securing revenues for grid resilience, which may involve novel business models and non-utility market participants; and
- the challenges that could threaten viability and cost-effectiveness and the solutions that could enable the successful contribution of each mode to grid resilience.

As emerging non-utility actors, such as owners of EV fleets and aggregators, become more active, it is important to understand their evolution and the kind of business models that can optimize their value through the grid. Non-utility market aggregators have been involved in distributed solar and demand response for more than a decade. They are now also consolidating around mobile energy storage (i.e., electric vehicles), stationary energy storage, microgrids, and other parts of the grid. In the solar market, consumers are becoming "prosumers"—both producing and consuming electricity, facilitated by the fall in the cost of solar panels. Grid-integrated vehicles are another form of "prosumership" where the vehicle owner can be a consumer as well as a provider of grid services.

Questions to be explored include:

1. Which mode of grid integration is likely to have the greatest impact on grid resilience?
2. What grid resilience services can each of these modes provide today and in the future?
3. Which models of non-utility participation would maximize grid resilience in terms of asset ownership, interactions with utilities, and the provision of mobility services?
4. What technological, socio-economic/financial, and regulatory challenges need to be overcome for a full deployment of G2V, V2B, and V2G?

3 Key Findings

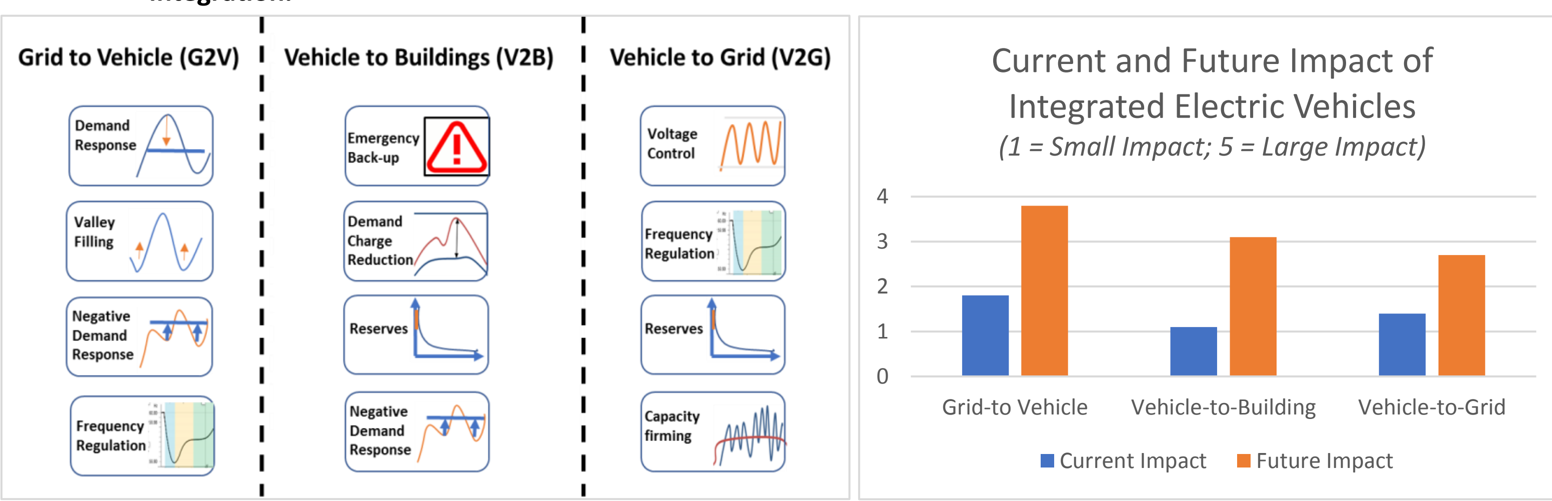
3.1 Types of Grid Resilience Services

Ten types of resilience and reliability services related to EV integration are identified and defined in Appendix A. This list is a subset of a much larger array of possibilities. For example, there are many different types of reserves that could be specified.

Figure 2 identifies 4 types of grid resilience services that appear to be closely aligned with each of the three modes of EV integration. [6] Some services are common to more than one mode of integration, such as frequency regulation which is common to both V2G and G2V. Other services are unique to a particular mode, such as back-up generation, where EVs can be used to power homes, hospitals, and shelters, thereby reducing the casualties and economic cost of grid disruptions.[7]

The four types of services are listed in rank order (from top to bottom) based on the potential for grid-integrated vehicles to provide grid resilience services, as evaluated by the EAC experts. The figure also identifies the survey responses of our experts on the potential of each EV integration mode to provide value to grid resilience now and in the future (specifically, 2030). Refer to Table 1 in Appendix B for more detail.

Figure 2: Types of grid resilience services and the overall potential impact of various modes of EV integration.



3.2 Alternative Business Models

An array of different business models exist that could be used to deliver resilience and reliability services to markets. There is an emerging role of non-utility participants operating in the EV-grid marketplace. The evolving market structure is combining consumers with third-party producers and aggregators in a variety of novel ways, some of which are consistent with the sharing economy. A core concept of the sharing economy is the ability to capture and redistribute the idle capacity of existing assets.[8] By increasing the usage of products and assets, economic productivity is enhanced. In most advanced economies, owners drive their cars only a few hours each day, offices are often empty, large sections of homes are unoccupied much of the time, stores have peak- and off-peak shopping hours, and power plants have substantial unutilized capacity.[9] Collaborative consumption could potentially put this excess capacity to better use.[10]

The EAC questionnaire asked respondents to consider alternative business models for grid-integrated vehicles; the results are shown in Table 2 found in Appendix B. “Aggregators contracting with fleet owners” was seen to be the most valuable approach for aggregators to deliver grid services. Warranty coverage by manufacturers and aggregators was viewed as the most helpful way to manage the impact of grid integration on the potential degradation of batteries.

3.3 Challenges to EVs as Sources of Grid Resilience

The EAC questionnaire asked respondents to consider three types of challenges to grid-integrated vehicles: (1) technological, (2) socio-economic/financial, and (3) policy/regulatory.
Survey participants expressed strong concerns about the degradation of batteries and the voiding of battery warranties with bidirectional charging. Alternatively, some respondents suggested that the damage to batteries could be reduced and battery quality could be maintained with proper monitoring: batteries that are “grid managed” can maintain their health and last longer than unmanaged batteries in EVs used just for mobility.

Because EVs can lead to surges in demand for charging power over space and time, owners of DC fast charging stations have to pay for transformer upgrades as well as “demand charges”. Payments to charging station owners and aggregators for ancillary services was also a concern, as was the challenge of valuing ancillary services in a vertically integrated market.

Additional concerns clustered around interoperability standards, communication standards, and cybersecurity as well as the well-documented role of range anxiety and access to charging infrastructure. See Table 3, found in Appendix B, for more detail.

3.4 Lessons from Past and Ongoing Pilot Projects and Simulations Related to Grid-Integrated Vehicles

In a G2V pilot, the BMW i ChargeForward, is an example where EV owners can “opt-in” for smart charging where the managed charging by BMW would help to provide demand response services to Pacific Gas & Electric (PG&E). The National Renewable Energy Laboratory used California’s Low Carbon Grid Study to quantify value to the grid from managed charging by using three levels of managed loads for 13 TWh of annual load from three million EVs in 2030. Simulation results show that management of the EV fleet’s aggregate load from unmanaged to 100% managed results in savings between $210 million and $660 million annually in generation system costs, depending on grid conditions.[11] There is also the possibility of distribution deferral—avoiding line upgrades and component capacity until a later date – which could mean real dollars for the utility.

A University of Delaware and PJM case study illustrates the ability of EVs to bid frequency regulation services into competitive markets. In a simulation assessment, Shinzaki, Sadano, Maruyama, and Kempton estimate that a vehicle could generate between $623 and $1,014 in V2G service revenue streams.[12] Others have estimated the monetary benefits to be in the range of $100–300 per year per participating vehicle.[13] This could potentially reduce the total cost of ownership of an electric vehicle.[14]

Oak Ridge National Laboratory is partnering with UPS on a DOE-funded project focused on developing high-power, bidirectional wireless charging for electric delivery trucks. Technology will allow power to flow both ways, so vehicle can power the electric grid for the UPS facility in the event of an electricity outage. The goal is a V2G mode, with 6.6 kW wireless power transfer to building or grid loads providing grid support functions or ancillary services that can strengthen grid resilience.[15]

The DOE's Vehicle Technologies Office (VTO) is funding vehicle/grid integration projects that cross multiple domains. VTO is assessing the impact of providing various grid services on EVs and key components such as batteries and power electronics.[16] For example, the National Renewable Energy Lab and the University of Delaware have developed an active state-of-charge management program that can ensure enough charge for the next trip and provide grid services, while reducing the effects of battery degradation over time and quantifying the impact of vehicle-to-grid technologies on a battery's lifespan.[17]

Finally, Nissan is working to deploy 6kW bi-directional charges in Japanese homes in the wake of Fukishima. They deployed 7,000 Nissan Leafs to provide 3-5 days of power for a household from each Leaf.

There is a significant economic and technical potential for integrating EVs with the power grid. Going forward, it will be crucial to assess the specific values and challenges associated with each ancillary service that these integrated vehicles can generate, in the context of different modes of EV integration.

4 Recommendations

Five recommendations emerged from discussions of this work product during the course of six monthly conference calls with the Smart Grid Subcommittee (SGS) and interim conference calls with subsets of the Subcommittee. The list of five recommendations does not reflect any rank ordering.

Recommendation #1: The DOE should increase support for research to create and harmonize standards needed for EVs to integrate with the grid and participate in the market, particularly with respect to bilateral exchanges.

This could include, for instance, coordination of a testbed for demonstration of standards interoperability. IEEE has identified 14 different interfaces with different functionalities amongst EVs, communication systems, and charging stations.[18] [19] Standards currently cover these different interfaces, but it is not clear that these standards regulating North American markets are sufficient for managing vehicle-to-grid transactions.[20]

Recommendation #2: The DOE should increase support for research to evaluate the range of possibilities for using EVs for grid services, effects at both the distribution and transmission level, mitigation techniques to avoid negative grid impacts, and impacts of bidirectional charging on the lifetime of EV batteries when used within such systems.

The voltage impact of growing EV penetration, fast charging, and bidirectional charging should be considered. For example, connecting EVs to the grid to provide frequency regulation could produce voltage fluctuation and harmonics pollution.[21] There are also concerns that bi-directional charging will lead to accelerated degradation of batteries, and as a result, OEMs typically nullify vehicle warrantees when owners deploy V2B and V2G modes of operation. The DOE should work with OEMs to assess the circumstances under which their warranty exclusions may be waived, especially for emergency situations. Enhancing grid resilience with integrated storage will require EV battery systems that manage energy storage, charge control, and communications as well as off vehicle power converter systems that control DC energy flow to and from the EV battery system.[22]

Recommendation #3: The DOE should commence a comprehensive economic study that analyzes US EV penetration scenarios, grid impacts and investment requirements to provide charging infrastructure and generation requirements.

Corresponding grid resilience and other societal benefits should be quantified as co-benefits of transportation electrification. Distribution capacity upgrades are likely needed to support EV charging. In addition, grid investment is required to support new peak demand. These distribution and generation investments may be used as leverage to create additional grid resiliency.

Recommendation #4: The DOE should increase support for research on the range of business models for EV charging infrastructure, policies that create barriers or incentives to each, and provide materials to guide state decision making for ownership, control and rate-basing methodology given the objective of increased reliability and resilience.

As EV adoption levels and grid integration become material, there is a need to better understand the pros and cons of alternative use cases that support different business models and provide different benefits for the grid, new businesses (aggregators), and the public. The development of the metrics for such assessment, and an understanding of the policy environment that supports or inhibits each business model in different parts of the country are also key needs. [23] [24]Ultimately, a "multi-sided market" may evolve to enable peer-to-peer energy transactions possibly spanning multiple local distribution areas.[25]

Recommendation #5: The DOE should fund additional V2G pilot projects to better understand these challenges, public acceptance, the costs and benefits to vehicle owners, and best practices to best optimize the outcome of electric transportation and grid infrastructure development.

While energy storage integration with the grid has been proven technically for numerous cases, using the storage in vehicles for grid support carries unknowns in terms of the impacts on the vehicle, acceptance by the owner and adoption by the utilities to pursue this strategy. The transportation needs of EVs create different state of charge (SOC) conditions as the vehicles move through the transportation system, and this feature is quite different from grid interactions with stationary energy storage.

References

[1] National Academy of Sciences, *Enhancing the Resilience of the Nation's Electricity System*, Washington, DC: National Academies Press (Sept. 2017), *available at* https://www.nap.edu/catalog/24836/enhancing-the-resilience-of-the-nations-electricitysystem.

[2] Advanced Energy Economy and Navigant Research. 2018. "Advanced Energy Now – 2017 Market Report".

[3] Elgowainy, Amgad, Jeongwoo Han, Jacob Ward, Fred Joseck, David Gohike, Alicia Lindauer, Tod Ramsden, Mary Biddy, Mark Alexander, Steven Barnhart, Ian Sutherland, Laura Verduzco, and Timothy J. Wallington. 2018. "Current and Future United States Light-Duty Vehicle Pathways: Cradle-to-Grave Lifecycle Greenhouse Gas Emissions and Economic Assessment," *Environmental Science and Technology,* 52 (4).

[4] These included valuable inputs provided by participants in a meeting on "Grid-Integrated Vehicles," co-hosted by Chattanooga's Electric Power Board and the Georgia Institute of Technology on March 1, 2018. https://cepl.gatech.edu/projects/sgp/GIV

[5] Anmol Soni and Karthik Kandasamy (Georgia Institute of Technology) provided valuable assistance with the development of the questionnaire of the DOE's Electricity Advisory Committee.

[6] Brown, Marilyn A., Shan Zhou, and Majid Ahmadi. 2018. "Governance of the Smart Grid: An international review of evolving policy issues and innovations," *Wiley Interdisciplinary Reviews (WIREs): Energy and Environment,* DOI: 10.1002/wene.290.

[7] Tomodachi. 2016. "Tokyo Aims to Realize Hydrogen Society by 2020." Japanese Government. Retrieved May 13, 2018 from https://www.japan.go.jp/tomodachi/2016/spring2016/tokyo_realize_hydrogen_by_2020.html

[8] Finley, K. (2013). Trust in the Sharing Economy: an exploratory study. University of Warwick.

[9] Bhushan, B. & S.K. Soonee. Utilisation of Idling Capacity of Captive Power Plants – A Viable Alternative. Annexure-B "open Access" in the Indian Context

[10] Demailly, D., & Novel, A.-S. (2014). The sharing economy: make it sustainable. *Iddri*, *3*(14), 30. Retrieved from http://www.phibetaiota.net/wp-content/uploads/2014/10/The-Sharing-Economy-and-Sustainability.pdf

[11] Zhang, Jiucai, Tony Markel, and Jennie Jorgenson. 2018. "Value to the Grid from Managed Charging based on California's High Renewables Study," IEEE PES Transactions on Power Systems.

[12] Shinzaki, S., Sadano, H., Maruyama, Y., & Kempton, W. (2015). *Deployment of vehicle-to-grid technology and related issues* (0148-7191).

[13] Richardson, D. B. Electric vehicles and the electric grid: a review of modeling approaches, Impacts, and renewable energy integration. *Renew. Sustain. Energy Rev.* **19**, 247–254 (2013).

[14] Lee, Dong-Yeon, Valerie M. Thomas, and Marilyn A. Brown. 2013. "Electric Urban Delivery Trucks: Energy Use, Greenhouse Gas Emissions, and Cost-Effectiveness," *Environmental Science and Technology,* 47(14) 8022-2030.

[15] Burak Ozpineci. 2018. "Technology Development: Updates, Challenges and opportunities," presentation to the EAC SGS, May 17.

[16] Lee Slezak. 2018. "Vehicle Technologies Office Grid and Infrastructure R&D," presentation to the EAC SGS, March 15.

[17] https://www.nrel.gov/esif/partnerships-university-of-delaware.html

[18] https://tec.ieee.org/standards

[19] NIST/SGIP Catalog of Standards - http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPCoSStandardsInformationLibrary

[20] Pratt, Richard, and Krishnan Gowri. 2012. "Vehicle to Grid Communication Development," PNNL-SA-94337. https://www.energy.gov/sites/prod/files/2014/03/f13/vss122_pratt_2013_p.pdf

[21] Falvo, Maria Carmen, Danilo Sbordone, Safak Bayram, and Michael Devetsikiotis. 2014. "EV Charging Stations and Modes: International Standards," International Symposium on Power Electronics, Electrical Drivers, Automation and Motion.

[22] California Public Utility Commission. 2017. "VGI Requirements Sub Group Final Report," September 6, http://www.cpuc.ca.gov/vgi/

[23] California Public Utility Commission. 2017. "Work Plan for Vehicle-Grid Integration Working Group," http://www.cpuc.ca.gov/vgi/

[24] https://www.afdc.energy.gov/bulletins/technology-bulletin-2015-08.html

[25] De Martini, Paul and Lorenzo Kristov. 2015. "Distribution Systems in a High Distributed Energy Resource Future, Ed. Schwartz, Lisa C. Vol. FEUR Report No. 2. 2015. LBNL-1003797.

https://emp.lbl.gov/publications?page=6

Appendix A: Definitions

Definitions of Resilience

There are various definitions of resilience provided by the National Infrastructure Advisory Council[25], the National Academy of Sciences[25], Argonne National Laboratory[25], PJM[25], and Presidential Policy Directive 21[25]. The Federal Energy Regulatory Commission (FERC) notes that commenters generally defined resilience similarly, focusing on the ability of the bulk power system to withstand or recover from disruptive events.[25]

Definitions of Resilience and Reliability Services

Service	Definition
Demand Response	Responding to the changes in prices or high demand by charging vehicles when the demand is lower
Valley Filling	Building loads during off-peak hours to help load shifting
Negative Demand Response	Dynamic charging can be used to support demand during low demand periods to support base load power
Coordinated Charging	Synchronizing the charging process in order to avoid demand surges
Demand Charge Reduction	Switching to car batteries during high demand periods can help reduce the demand charges for users
Reserves	The low ramp-up speeds allow vehicle batteries to provide spinning, non-spinning and supplementary reserves
Emergency Back-up	The battery of the vehicle can be used as a storage device that feeds back into the grid in the event of outages
Capacity Firming	Using storage facilities to manage the variable generation, especially with the integration of renewables in the power generation mix
Voltage Control	Using the battery storage and two-way flow help maintain the voltage at the users' end
Frequency Regulation	Ramping up or down based on the changes in frequency and difference in power demand and supply

Appendix B: Tables and Figures

Table 1: Potential for Grid-Integrated Vehicles to Provide Grid Resilience Services

G2V	Mean Value	V2B	Mean Value	V2G	Mean Value
Demand response	3.8	Emergency back-up	3.3	Voltage control	2.9
Valley filling	3.5	Demand charge reduction	2.8	Frequency regulation	2.8
Negative demand response	2.7	Reserve provision	2.2	Reserve provision	2.3
Frequency Regulation	2.6	Negative demand response	1.9	Capacity firming	2.2

Table 2: Alternative Business Models

Possible approach that aggregators could use to deliver grid services	Mean Value	Models might be most helpful to manage the impact on batteries	Mean Value
Aggregators leasing cars to customers	2.4	Battery swapping	3.1
Aggregators providing subscription services for charging	2.9	Aggregator warranty-coverage	3.3
Aggregators contracting with fleet owners	4.3	Manufacturer warranty-coverage	3.5
Aggregators contracting with ride share services	3.3	Fleet owner warranty-coverage	2.9
Aggregators contracting with car rental services	3.1	Utility warranty-coverage	2.1

Table 3: Assessment of Challenges to Grid-Integrated Vehicles

Technological Challenges	Mean Value	Socio-economic/ Financial Challenges	Mean Value	Policy/Regulatory Challenges	Mean Value
Degradation of batteries	3.9	Transaction costs with EV owners	4	Tariff or rate design policies	3.5

Surge in demand for power with DC fast charging	3	Payments to charging station owners and aggregators for ancillary services	3.7	Valuing ancillary services in a vertically integrated market	3.3
DC Compatibility with bidirectional flows	2.7	Least cost utility planning and financing	3.3	Open source architecture platform	2.8
Latency following signal inputs from aggregators	2.7	Range anxiety	4.1	Creating resilience service products in wholesale markets	2.8
Communication protocols	3	Access to charging infrastructure	3.2	Cybersecurity	3.3
Interoperability standards	3.6	Voiding of battery warranty with bidirectional charging	4.3	Certification of charging infrastructure	3
Interoperability standards	2.9				
Architectural issues	3				

Figure 3. Opposition and Support from Stakeholders
(1=Strongly Oppose, 3=Neutral, and 5=Strongly Support)