**Annotated Bibliography on Grid Integrated Vehicles**

**Anmol Soni and Marilyn Brown, Georgia Institute of Technology**

**January 30, 2018**

**Overview**

**Fitzgerald, G., Nelder, C., & Newcomb, J. (2016). Electric Vehicles as Distributed Energy Resources, *Rocky Mountain Institute***

The electric vehicle market is one of the most rapidly changing and fastest growing high-tech sectors in the global economy, representing the beginnings of a demand-side opportunity like no other: intelligent, interactive electricity demand.

**IEA. (2011). Technology Roadmap: Electric and plug-in hybrid electric vehicles. Paris: *International Energy Agency.***

Electric and plug-in hybrid vehicles (EVs and PHEVs), if coupled with low greenhouse gas (GHG) electricity generation, can help cut energy (particularly petroleum) use and CO2 significantly, especially in the 2030-2050 timeframe – but key actions must begin now to achieve interim targets and thus substantial market shares in the long-term. The vision of this roadmap is to achieve widespread adoption and use of EVs and PHEVs worldwide by 2050, and if possible well before. The primary role of this EV/PHEV Roadmap is to help establish a vision for technology deployment; set approximate, feasible targets; and identify steps required to get there. It also outlines the role for different stakeholders and how they can work together to reach common objectives, and the role for government policy to support the process.

The analysis in the roadmap is based on IEA’s ETP 2DS scenario, updated in the IEA report Transport, Energy and CO2: Moving Toward Sustainability (Autumn 2009). This scenario targets a 50% reduction in CO2 worldwide by 2050 relative to 2005 levels. For transport, a 30% reduction is achieved via efficiency improvements, along with the introduction of new types of vehicles and fuels. For EVs and PHEVs, sales begin to grow rapidly after 2015 and reach a combined 7 million per year by 2020, and 100 million by 2050, over half of all cars sold around the world in that year.

**IEA. (2017). Global EV outlook 2017: Two million and counting. Paris: *International Energy Agency*.**

The Global EV Outlook 2017 provides insights on recent EV technology, market, and policy developments, in particular with regards to the sector's status outlined previously in the [Global EV Outlook 2016](https://www.iea.org/publications/freepublications/publication/global-ev-outlook-2016.html). Detailed information for the past five to ten years on EV registrations (vehicle sales), number of EVs on the road, and modal coverage across the most relevant global vehicle markets is provided. The analysis also looks at the availability and characteristics of Electric Vehicle Supply Equipment (EVSE). The Global EV Outlook 2017 reports on battery cost and energy density improvements, holding promises for further progress in EV performance and cost-competitiveness. A review and discussion of key elements on policy support for both EVs and EVSE is included, identifying policy requirements for a successful transition to mass market adoption. Finally, the report assesses the potential of EVs in CO2 emissions reduction in the transportation sector, in conjunction with requirements for successful grid integration and synergies with low-carbon, renewable electricity.

**Amsterdam Round Tables and McKinsey and Company. (2014). Evolution: Electric vehicles in Europe:**

**gearing up for a new phase?**

**Technology**

**Kempton, W., & Tomić, J. (2005). Vehicle-to-grid power fundamentals: Calculating capacity and net revenue. *Journal of Power Sources*, 144(1), 268-279.**

As the light vehicle fleet moves to electric drive (hybrid, battery, and fuel cell vehicles), an opportunity opens for “vehicle-to-grid” (V2G) power. This article defines the three vehicle types that can produce V2G power, and the power markets they can sell into. V2G only makes sense if the vehicle and power market are matched. For example, V2G appears to be unsuitable for baseload power—the constant round-the-clock electricity supply—because baseload power can be provided more cheaply by large generators, as it is today. Rather, V2G's greatest near-term promise is for quick-response, high-value electric services. These quick-response electric services are purchased to balance constant fluctuations in load and to adapt to unexpected equipment failures; they account for 5–10% of electric cost—$ 12 billion per year in the US. This article develops equations to calculate the capacity for grid power from three types of electric drive vehicles. These equations are applied to evaluate revenue and costs for these vehicles to supply electricity to three electric markets (peak power, spinning reserves, and regulation). The results suggest that the engineering rationale and economic motivation for V2G power are compelling. The societal advantages of developing V2G include an additional revenue stream for cleaner vehicles, increased stability and reliability of the electric grid, lower electric system costs, and eventually, inexpensive storage and backup for renewable electricity.

**Shinzaki, S., Sadano, H., Maruyama, Y., and Kempton, W., "Deployment of Vehicle-to-Grid Technology and Related Issues," *SAE Technical Paper* 2015-01-0306, 2015, doi:10.4271/2015-01-0306.**

In order to reduce emissions and enhance energy security, renewable power sources are being introduced proactively. As the fraction of these sources on a power grid grows, it will become more difficult to maintain balance between renewable power supply and coincident demand, because renewable power generation changes frequently and significantly, depending on weather conditions. As a means of resolving this imbalance between supply and demand, vehicle-to-grid (V2G) technology is being discussed, because it enables vehicles to contribute to stabilizing the power grid by utilizing on-board batteries as a distributed energy resource as well as an energy storage for propulsion. The authors have built a plug-in vehicle with a capability of backfeeding to the power grid, by integrating a bi-directional on-board AC/DC and DC/AC converter (on-board charger) and a digital communication device into the vehicle. The vehicle is interconnected to a power regulation market in the United States. By participating in the regulation market, the authors verify that this V2G-capable car is able to create a value of more than $100/kW annually by charging and discharging power. In order to widely adopt V2G technology in the real world, it is necessary to establish an overall system that enables adoption of the technology by interconnecting individual vehicles, users, grid operators, utilities, and governmental organizations. Standardization is also important for large-scale deployment of the technology, an area in which SAE has already been moving forward.

**Policy & Regulatory Analysis**

**Holland, S. P., Mansur, E. T., Muller, N. Z., & Yates, A. J. (2015). *Environmental benefits from driving electric vehicles?*(No. w21291). National Bureau of Economic Research.**

Electric vehicles offer the promise of reduced environmental externalities relative to their gasoline counterparts. We combine a theoretical discrete-choice model of new vehicle purchases, an econometric analysis of the marginal emissions from electricity, and the AP2 air pollution model to estimate the environmental benefit of electric vehicles. First, we find considerable variation in the environmental benefit, implying a range of second-best electric vehicle purchase subsidies from $3025 in California to -$4773 in North Dakota, with a mean of -$742. Second, over ninety percent of local environmental externalities from driving an electric vehicle in one state are exported to others, implying that electric vehicles may be subsidized locally, even though they may lead to negative environmental benefits overall. Third, geographically differentiated subsidies can reduce deadweight loss, but only modestly. Fourth, the current federal purchase subsidy of $7500 has greater deadweight loss than a no-subsidy policy.

**Chandra, A., Gulati, S., & Kandlikar, M. (2010). Green drivers or free riders? An analysis of tax rebates for hybrid vehicles. *Journal of Environmental Economics and Management*, *60*(2), 78-93.**

We estimate the effect of tax rebates offered by Canadian Provinces on the sales of hybrid electric vehicles. We find that these rebates led to a large increase in the market share of hybrid vehicles. In particular, we estimate that 26% of the hybrid vehicles sold during the rebate programs can be attributed to the rebate, and that intermediate cars, intermediate SUVs and some high performance compact cars were crowded out as a result. However, this implies that the rebate programs also subsidized many consumers who would have bought either hybrid vehicles or other fuel-efficient vehicles in any case. Consequently, the average cost of reducing carbon emissions from these programs is estimated to be $195 per tonne.

**Gallagher, K. S., & Muehlegger, E. (2011). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. *Journal of Environmental Economics and management*, *61*(1), 1-15.**

Federal, state, and local governments use a variety of incentives to induce consumer adoption of hybrid-electric vehicles. We study the relative efficacy of state sales tax waivers, income tax credits, and non-tax incentives and find that the type of tax incentive offered is as important as the generosity of the incentive. Conditional on value, sales tax waivers are associated with more than a ten-fold increase in hybrid sales relative to income tax credits. In addition, we examine how adoption varies with fuel prices. Rising gasoline prices are associated with greater hybrid vehicle sales, but this effect operates almost entirely through high fuel-economy vehicles. By comparing consumer response to sales tax waivers and estimated future fuel savings, we estimate an implicit discount rate of 14.6% on future fuel savings.

**Yang, Z., Slowik, P., Lutsey, N., & Searle, S. (2016). Principles for effective electric vehicle incentive design. ICCT**

Faced with declining air quality and their own climate goals, many governments around the world have sought to accelerate the market for electric vehicles. There are various tools used by the governments to promote electric vehicles, but because the upfront costs of electric vehicles are higher than their conventional counterparts, the issue that tends to get the most attention is the fiscal incentive.

The types of incentives used, however, vary greatly. This analysis assesses the best practices in the design of electric vehicle incentives, comparing them across major markets in North America, Europe, and Asia. It studies the different aspects of electric vehicle incentives, including their magnitude, type, eligibility by technology type, timing, and durability. The authors quantify both what incentives are in place and the link between the incentives and electric vehicle uptake.

Based on the findings, the authors outline four principles that are emerging to define the optimal design of electric vehicle incentives. These include making the value of the incentives crystal clear to consumers and dealers, and ensuring that the incentives are available to the full target market.

More than 500,000 electric vehicles were sold globally in 2015–up from just hundreds in 2010–and most of these electric vehicles were sold in markets where well-designed fiscal incentives are in place. As electric vehicles are likely to be a key part of the transport sector’s ability to meet long-term decarbonization goals, a key question is how quickly electric vehicles could move beyond this early higher cost stage to larger volume, greater economies of scale, and lower cost. Until then, optimally designed incentives are bringing the effective cost of electric vehicles closer to those of conventional vehicles, helping to more rapidly establish a new electric-drive fleet.

**The Greenlink Group. (2017). The Economic Opportunities of Electric Vehicles in Georgia. Available at <** [**https://docs.wixstatic.com/ugd/aad50d\_f60b1f64a2ba49b397bbebff91535809.pdf**](https://docs.wixstatic.com/ugd/aad50d_f60b1f64a2ba49b397bbebff91535809.pdf)**>**

The study examines the implications of introducing the fee on registration of electric vehicles in Georgia and assesses the macroeconomic implications of the policy on GDP and employment.

**Langton, A. & Crisostomo, M. (2014) Vehicle - Grid Integration: A Vision for Zero-Emission Transportation Interconnected throughout California’s Electricity System. *Emerging Procurement Strategies Section.* California Public Utilities Commission.** Available at <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M080/K775/80775679.pdf>

**Hall, D., & Lutsey, N. (2017). Literature review on power utility best practices regarding electric vehicles. ICCT**

The report makes the following points:

With proper planning, electric vehicles’ benefits to utilities outweigh their costs

Rate structures can influence electric vehicle charging behavior and grid impacts

Smart charging can unlock the full benefits of electric vehicles.

Greater regulatory clarity and standardization is needed. U

 **Utilities can play a role in advancing the hydrogen economy.**

**Hall, D., Moultak, M., & Lutsey, N. (2017). Electric Vehicle Capitals of the World: Demonstrating the Path to Electric Drive. *White Paper*. International Council on Clean Transportation**

The paper provides three main findings:

 EV sales are concentrated in 14 cities (one third of the global sales are in these cities)

 A comprehensive set of policies are adopted in these cities

Even after including the emissions from upstream power generation - EVs can help reduce emissions from the transport sector

**Socio-economic & Financial Analysis**

**Sovacool, B., Noel, L., Axsen, J., & Kempton, W. (2017). The neglected social dimensions to a vehicle-to-grid (V2G) transition: A critical and systematic review. Environmental Research Letters.**

Vehicle-to-grid (V2G) refers to efforts to bi-directionally link the electric power system and the transportation system in ways that can improve the sustainability and security of both. A transition to V2G could enable vehicles to simultaneously improve the efficiency (and profitability) of electricity grids, reduce greenhouse gas emissions for transport, accommodate low-carbon sources of energy, and reap cost savings for owners, drivers, and other users. To understand the recent state of this field of research, here we conduct a systematic review of 197 peer-reviewed articles published on V2G from 2015 to early 2017. We find that the majority of V2G studies in that time period focus on technical aspects of V2G, notably renewable energy storage, batteries, or load balancing to minimize electricity costs, in some cases including environmental goals as constraints. A much lower proportion of studies focus on the importance of assessing environmental and climate attributes of a V2G transition, or on the role of consumer acceptance and knowledge of V2G systems. Further, there is need for exploratory work on natural resource use and externalities, discourses and narratives as well as social justice, gender, and urban resilience considerations. These research gaps need to be addressed if V2G is to achieve the societal transition its advocates seek.

**Sovacool, B. K., Axsen, J., & Kempton, W. (2017). The future promise of vehicle-to-grid integration: a sociotechnical review and research agenda. Annual Review of Environment and Resources, 42(1).**

Vehicle-grid integration (VGI) describes various approaches to link the electric power system and the transportation system in ways that may benefit both. VGI includes systems that treat plug-in electric vehicles (PEVs) as controllable load with a unidirectional flow of electricity, such as “smart” or “controlled” charging or time-of-use (TOU) pricing. VGI typically encompasses vehicle-to-grid (V2G), a more technically advanced vision with bidirectional flow of electricity between the vehicle and power grid, in effect treating the PEV as a storage device. Such VGI systems could help decarbonize transportation, support load balancing, integrate renewable energy into the grid, increase revenues for electricity companies, and create new revenue streams for automobile owners. This review introduces various aspects and visions of VGI based on a comprehensive review. In doing so, it identifies the possible benefits, opportunities, and barriers relating to V2G, according to technical, financial, socio-environmental, and behavioral components. After summarizing our sociotechnical approach and the various opportunities and barriers indicated by existing literature, we construct a proposed research agenda to provide insights into previously understudied and unstudied research objectives. We find that the majority of VGI studies to date focus on technical aspects of VGI, notably on the potential of V2G systems to facilitate load balancing or to minimize electricity costs, in some cases including environmental goals as constraints. Only a few studies directly investigate the role of consumer acceptance and driver behavior within such systems, and barely any studies address the need for institutional capacity and cross-sectoral policy coordination. These gaps create promising opportunities for future research.