Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California

by

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Executive Summary

Electric-drive vehicles can become an important resource for the California electric utility system, with consequent air pollution, system reliability, and economic benefits. We refer to electric power resources from vehicles as "Vehicle to Grid" power (V2G). The economic value of some forms of V2G appear high, more than enough to offset the initially higher costs of electric-drive vehicles, thus having the potential to accelerate their introduction. To realize this potential, some coordination of vehicle and infrastructure planning will be needed.

This study calculates three parameters of electric drive vehicles (EDVs) which are important for their use by the electric system: resource size, availability, and economic potential. Economic potential was calculated for three power markets: peak power, spinning reserves, and regulation services. Vehicles were not found to be competitive for baseload power. The analysis uses California electricity market prices for three years—1998, 1999, and 2000—as well as historical electric utility experience. This three-year comparison insures that recent disruptions, and historically atypical prices, in the 2000 California electricity market do not bias the results. In addition to electricity markets, "customer side of the meter" strategies are analyzed, in which vehicle power offsets time-of-use charges, demand charges, and interruptible rates. These multiple

calculations of the value of EDV power make the conclusions about its economic viability more robust.

This report analyzes V2G power from three types of EDVs—battery, hybrid, and fuel cell. Battery EDVs can store electricity, charging during low demand times and discharging when power is scarce and prices are high. Fuel cell and hybrid EDVs are sources of new power generation. For economic reasons they would sell power only when prices are high. Battery and plug-in hybrid EDVs can also sell regulation services, which involves little or no net battery discharge. In the terminology of the California Air Resources Board (CARB), battery and fuel cell EDVs are considered Zero Emission Vehicles (ZEV), hybrids are considered Advanced Technology Partial ZEV (AT-PZEV), and battery EDVs are often referred to simply as EVs.

The report begins by describing the technical requirements needed to realize the most value from vehicle power. These include on-board power electronics, plug-to-vehicle connections, and communications facilities ("telematics"). The required technologies are all in production or in prototype vehicles, although they have not been put together in the ways we propose. We also discuss bridge strategies; for example, the conductive charging stations now being installed for recharging battery vehicles will later be valuable for carrying power from hybrid and fuel cell vehicles to the grid. Implications for current industry directions are also discussed; for example, existing on-board conductive chargers can be used for V2G whereas, current inductive chargers cannot.

Formulas are derived to calculate the power capacity of each vehicle type. Calculated capacity depends on the charger capacity, residential and commercial electrical service capacity, fuel or electricity needed for the next trip, whether a continuous piped gaseous fuel source is connected to the vehicle, and other factors. The battery vehicles have power capacity on the order of 10 kW and fuel cell vehicles have up to approximately 40 kW. The hybrid vehicles are of interest when operating in the motor-generator mode, fueled by gasoline or a natural gas line, with power capacity up to 30 kW. For many scenarios, output is limited by line capacity to the existing 6 kW charging stations, or near term standards for 16 kW.

We calculate total expected resource size from CARB requirements for electric drive vehicles. In the year 2004, the required quantities of vehicles in California would represent 424 MW of generating capacity, and in year 2008 they would represent over 2,000 MW (or 2 gigawatts). The latter figure is the equivalent output of two large nuclear plants running at full power, or about 4% of current California electric generating capacity. As another point of comparison, a Stage 3 emergency occurs when electricity generation is within 1.5% of electricity consumption. In the California Independent System Operator (CAISO) territory, rolling blackouts have been used to recover roughly 0.5% of a 40 GW peak, or some 200 MW. By year 2004, the EDV fleet would represent twice this capacity.

One conceptual barrier to understanding vehicles as a power source is an initial belief that their power would be unpredictable or unavailable because they would be on the road. Although any one vehicle's plug availability is unpredictable, the availability of thousands or tens of thousands of vehicles is highly predictable and can be estimated from traffic and road-use data. For example, peak late-afternoon traffic occurs during the hours when electric use is highest (from 3-6 pm). A supposition one might have from

driving, that the majority of the vehicles are on the road during rush hour traffic, is false. We calculate that over 92% of vehicles are parked and thus potentially available for V2G power production, even during peak traffic hours of 3-6 pm.

The cost of electricity generated by each EDV type is estimated. Battery vehicles can provide electricity to the grid at a cost of $0.23/kWh for current lead-acid batteries, $0.45/kWh for the Honda EV Plus with nickel metal hydride (NiMH) batteries, and $0.32/kWh for the Th!nk City car with nickel cadmium (NiCd) battery. The fuel cell vehicle can generate electricity at a cost ranging between $0.09 – $0.38 kWh, the wide range depending on the assumed cost of H_2, with the lower figure based on the longer-term assumption of a mature hydrogen market. A fuel cell vehicle with hydrogen recharge through a garage reformer could generate electricity at $0.19/kWh from natural gas (at $0.84/therm). The hybrid vehicles in motor-generator mode can generate electricity at a cost of $0.21/kWh if fueled with gasoline (at $1.50 per gallon) and at $0.19/kWh if fueled with natural gas. Based only on these simple costs per kWh, it appears that in the near term the most attractive EDV types are the lead-acid battery vehicle, a fuel cell vehicle recharged from a natural gas reformer, and the hybrid vehicle. However, the simple cost per kWh comparison does not provide an adequate evaluative framework.

The cost of electricity from the EDVs noted above is too high to be competitive with baseload power, which typically has a range from $0.03–0.05/kWh. EDV power is competitive in three other markets: "peak power" (during peak demand periods), spinning reserves, and regulation services. The latter two electricity markets are called "ancillary services," and in each, the power producer is paid a contract price for being connected and available, in addition to per kWh energy payments. For each combination of vehicle and power market, we calculate the value of the power in the market and the cost to the vehicle owner for providing power, assuming V2G power is produced only when revenue will exceed cost. This method is more comprehensive than earlier methods that used avoided costs (Kempton and Letendre 1997) or retail time-of-use rates (Kempton and Kubo 2000). Other benefits, including reduced air pollution and increased reliability of the electric system, are not included in the economic calculations, nor are transaction costs. Calculation of vehicle owner costs is comprehensive, including capital costs of any additional equipment required, fuel, and shortening of battery pack and internal combustion engine lifetime due to additional use.

Abbreviated findings are summarized in Table ES.1 below. The top dollar figure in each cell is the net profit (revenue minus costs). This table assumes mid-values and does not reflect ranges, uncertainties or assumptions. Not all vehicles analyzed are summarized here and the current is limited to Level 3AC charging stations (16.6 kW and slightly higher for fuel cell vehicles). Also, the vehicle specifications draw from middle-ranges, the revenues assume 1998 market prices for spinning reserves and regulation services, and an industry rule-of-thumb for peak prices. Battery and hybrid vehicle costs include costs of degradation of the battery or engine, but fuel cell vehicles do not. The wide cost ranges for the fuel cell vehicle reflect the range in estimates for hydrogen costs.

Table ES.1 Vehicle owner's annual net profit from V2G; these are representative mid-range figures extracted from full analysis in the report. Key: $net (revenue – cost).

	Peak power	Spinning reserves	Regulation services
Battery, full function	$267 (510 – 243)	$720 (775 – 55)	$3,162 (4479 – 1317)
Battery, city car	$75 (230 – 155)	$311 (349 – 38)	$2,573 (4479 – 1906)
Fuel cell, on-board H_2	$-50 (loss) to $1,226 (2200 – 974 to 2250)	$2,430 to $2,685 (3342 – 657 to 912)	$-2,984 (loss) to $811 (2567 – 1756 to 5551)
Hybrid, gasoline	$322 (1500 – 1178)	$1,581 (2279 – 698)	$-759 (loss) (2567 – 3326)

From this summary table alone, one notices that some vehicles are better suited than others for individual power markets. This indicates that matching the vehicle type to power market is important, as it is possible to both gain and lose money.

Taking the three markets in turn, peak power is the least promising. In our model, battery-powered vehicles serve the peak power market by charging their batteries when demand is off-peak and price is low (*e.g.*, 4.5 ¢/kWh) and selling power to the grid when the price is high (*e.g.*, over 30 ¢/kWh). The fueled vehicles sell peak power when power prices are above the costs to produce power. Although the table shows potential profits by the historical rule of thumb, for two of the three years of actual prices we find that the price was never high enough to justify selling peak power.

Spinning reserves shows economic viability for most vehicles, and for all those shown in Table ES.1. Net revenues for the spinning reserve market is particularly large for the fueled vehicles and is relatively insensitive to fuel prices due to the contract payments.

Regulation services involve higher numbers, for both revenue and cost, because vehicles can sell regulation more of the time. The battery vehicles appear to be especially suitable for regulation because their shallow cycling causes less battery degradation, and because batteries experience very little discharge when providing both regulation up and regulation down. Plug-in hybrids with range similar to the city car would have economics similar to the city car when running V2G in battery mode. The estimated net value of regulation services from battery EDVs is several thousand dollars per year.

As the EDV fleet grows, it will begin to saturate these power markets. We estimate that the CAISO market for regulation services, the highest value market, could be met with 109,000 to 174,000 vehicles, and spinning reserves with an additional 76,000 to 273,000 vehicles. Peak power could be a still larger market, but only at lower V2G costs than currently projected. These numbers represent a small fraction of the total vehicle fleet in California, but they should be sufficient to stimulate more than a decade of projected sales, past the time that production volumes bring down EDV sticker prices.

Vehicles can provide ancillary services of a higher quality than currently available— fast response, available in small increments, and distributed. Our discussions with CAISO staff suggest that vehicle power could open new, high value markets for ancillary services. If new, high value electricity markets are realized, our calculations of value and market size may be too low. In addition, the demand for and value of V2G power will increase in the future as intermittent renewable energy becomes a larger fraction of electric generation.

In addition to considering electricity markets, we analyze the value of EDV power on the customer side of the meter. Any commercial electricity customer can implement this immediately without the need for regulatory or tariff changes. On the other hand, it requires a high level of interest and management on the part of the electricity customer. The potential for customer-side of the meter V2G exists because current electricity rates include three tariffs that place a premium on power at certain times: time–of–use rates, demand charges, and interruptible rates. We evaluate this opportunity based on published electricity rates for four California utility companies: Pacific Gas & Electric, Southern California Edison, Los Angeles Department of Water and Power, and the Sacramento Municipal Utility District.

Based on the existing utility rate structures, we find that financial gains of V2G from the customer side of the meter would be small or negative for most residential customers. Commercial and industrial (C&I) customers, unlike residential customers, have rates that typically include a demand charge in $/kW, added to their energy charge in $/kWh. These demand charges are often the largest component of a C&I customer's monthly electric bills. We find that such customers, if they have infrequent or short demand peaks, could realize economic benefits from V2G power. That is, bill savings can exceed the cost of power from on-site EDVs. Examining a database on hourly electrical load distinguished by business types, we find only one industrial type and several commercial types have sharp enough peaks to justify V2G to offset demand charges. A more refined inventory of the number of C&I customers with potential for customer-side of the meter V2G would require more disaggregated load data (per building and per day) than we found available from public sources.

Overall, we conclude that all three types of EDVs studied represent a significant source of electric power for the electric grid. The largest value is in ancillary services such as spinning reserves and regulation. For battery and fuel cell vehicles, and possibly plug-in hybrids, the net value of this power is over $2,000 annually per vehicle, enough to quickly and economically usher in the era of a low- and zero-pollution light vehicle fleet.

Several policy issues are raised by this analysis. Initially, demonstration projects would help answer questions which are not amenable to the paper calculation approach of the current report. Also, some policy review would be helpful now. From the grid side, it would be appropriate to review rate structures and interconnect and safety standards in order to lay out changes or additions appropriate for V2G power. Charging station infrastructure planning should similarly be reviewed for its application to V2G power. From the vehicle side, we observe that no current production EDV has V2G capability. The incremental costs, for battery vehicles in particular, are exceptionally small (low hundreds of dollars per vehicle)—assuming that V2G would be designed in, not added later, and that telematics are being put on-board for independent reasons. By contrast, as

an add-on, the entire power electronics unit might need replacement at extremely high cost. This suggests that some incentives for vehicle V2G capabilities may be appropriate, even before a market for V2G develops. Finally, since the whole concept of V2G is predicated on interconnecting two distinct industries with distinct business models and separate regulatory bodies, near-term coordination across agencies (CARB, CEC, CAISO and/or CPUC) and across industries (electric utilities, automotive components, and automobile OEMs) would seem essential.

A copy the full report is available in PDF (Portable Document Format) at the following web site, which also has other documents and resources on vehicle-to-grid power.

`http://www.udel.edu/V2G`

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