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The Development of a Charge Protocol to Take Advantage of Off- and On-Peak Demand Economics at Facilities

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CONTENTS

FIGURES

TABLES

ACRONYMS

AC	alternating current
APS	Arizona Public Service
DC	direct current
EV	electric vehicle
ESS	energy storage system
PHEV	plug-in electric vehicle
SOC	state of charge
TOU	time of use
UDDS	Urban Dynamometer Driving Schedule
V2B	vehicle to building
V2G	vehicle to grid

The Development of a Charge Protocol to Take Advantage of Off- and On-Peak Demand Economics at Facilities

1. INTRODUCTION

Battelle Energy Alliance, LLC (BEA) is furnishing technical support and research assistance to the U.S. Department of Energy (DOE) related to the DOE objective of enabling a full range of affordable grid-connected electric drive cars and light trucks, as well as the energy infrastructure required for these vehicles. The end objectives are the reduced dependence of the national personal transportation system on imported oil and minimization of harmful vehicle emissions, without sacrificing freedom of mobility and freedom of vehicle choice.

This document reports the work performed for BEA as part of its management of the Idaho National Laboratory and DOE's Advanced Vehicle Testing Activity, including the development of a charge protocol to take advantage of off- and on-peak demand economics at facilities. The work also involved understanding the experimental results of the other tasks in order to take advantage of the economics of electricity pricing differences between on and off-peak hours and the demonstrated charging and facility energy demand profiles. To undertake this task and to demonstrate the feasibility of a plug-in hybrid electric vehicle (PHEV) and electric vehicle (EV) bi-directional electricity exchange potential, BEA requested ECOtality North America to use the data from a demand and energy study to focus on reducing the electrical power demand of the charging facility. The use of delayed charging and vehicle-to-grid (V2G) and vehicle-to-building (V2B) operations were to be considered.

V2G and V2B are developments currently under consideration for addition to the so-called "smart grid," in which the flow of electricity is no longer simply in one direction (i.e., from utility to consumer). Even more importantly, communication between utilities and consumers permits optimized and judicious allocation and usage of electricity resources. The implementation of this functionality is no small endeavor, and there are many organizations currently investigating all aspects of the smart grid topic. The objective of this study is to elucidate the economics of bi-directional charging of an EV by developing a charge/discharge profile that takes the Arizona Public Service (APS) time-of-use (TOU) rates into consideration.

1.1 Vehicle to Grid and Vehicle to Building Motivation

Development of the charge/discharge protocol was done for both the V2G and V2B systems from three perspectives: (1) the utility, (2) the building owner, and (3) the vehicle owner. All three stakeholders will have different reasons to embrace or reject V2G or V2B arrangements, as discussed in the following subsections.

1.1.1 Utility

The utility is likely to find bi-directional charging of PHEVs and EVs attractive for two reasons: (a) storage for renewable energy and (b) an electricity source to meet peak electricity demand. Electricity storage is seen as one of the main factors currently preventing widespread adoption of renewable energy. However, if the energy storage systems (ESSs) in PHEVs and EVs could be used for storage, it would allow electricity production and sale from an intermittent renewable source (such as wind or solar) that may not coincide with daily peak usage and that would otherwise be wasted. Meeting the demands of peak power currently is a very expensive obligation for utilities. If vehicle ESSs could be charged during off-peak times and then used during the daily peak usage to provide electricity, the utility could potentially forego the need to ramp up a "spinning reserve" plant or start up a peaking plant, which would save on operations and maintenance costs. Furthermore, if the electricity storage resource was reliably available, the utility could drastically reduce the growth in peak power demand, and new peaking plant facilities could be postponed and introduced more slowly. Therefore, the potential benefits of bi-directional charging to a utility include both capital and operations and maintenance costs.

It is important to note that the benefits of bi-directional charging would be different for V2G and V2B functionality. In a V2G situation, both of the benefits described above would be accrued, because electricity can be stored and sent to the grid (and shunted to nearby customers) at the behest of the utility. In order for the full benefits of V2G to be realized, there must be communication with the off-board vehicle charger and grid so the timing of charging and discharging the ESS can be controlled remotely by the utility[a]. The attractiveness of V2G for a utility is mainly driven by price. The price paid to the building owner, who would otherwise use the stored electricity to offset the building peak demand, plus the price paid to the vehicle owner for extra cycling of the vehicle ESS.

In a V2B scenario, the utility is not directly involved in the bi-directional electricity flow and the building owner uses the bi-directional capability to reduce the building demand during on-peak times. The attractiveness of V2B is less for a utility because only peak demand from the specific building is reduced and no electricity storage is made available to the utility. On the other hand, the complexity of the system is reduced because coordination of, and communication between, the off-board vehicle chargers and electrical grid is no longer necessary.

Depending on the economics of the arrangements, it is likely that a utility would pursue V2G and support V2B. However, one of the main concerns for a utility in terms of charging a large fleet of EVs is the possibility of overloading individual transformers if too many Level 2 or Level 3 chargers were to draw from one transformer. This concern is outside of the scope of this study, but care will have to be taken to ensure that overloading does not occur.

1.1.2 Building Owner

The interests of the building owner are different than those of the utility under the V2G and V2B scenarios. In the V2G situation, the building owner is merely a conduit for the utility to access the vehicle ESS and does not have control over when the vehicle is charged or discharged. In this case, the only direct benefit to the building owner occurs if the time when the vehicle is charged has a lower electricity rate than the time when the vehicle is discharged, thus reducing the overall building electricity bill. It is possible that a building owner and utility could enter into an agreement to make the arrangement more attractive to the building owner, who might otherwise have little monetary incentive to provide bi-directional chargers on the building premises. Such an arrangement could include having the chargers installed free of charge and having a flat rate paid for making the vehicle ESSs available. In a V2B situation, the building owner controls the timing and power levels of the vehicle ESS charging and discharging. This control would allow the building owner to reduce the amount of electricity consumed during on-peak hours; the utility would not be involved in this arrangement. Similar to the V2G case, the building owner would benefit from V2B capability mostly on the electricity bill; the difference between the two situations is that with V2B, the building owner could control the charging/discharging to greater advantage.

The building owner will find both V2G and V2B attractive if there is a large difference between on and off-peak electricity rates and if the capital costs of purchasing and installing the bi-directional

[a] The Society of Automotive Engineers standard for vehicle charging is J1772, "Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler." No provision for communication in Level 2 charging currently is included. The standard for Level 3 charging is still under development by the Society of Automotive Engineers.

chargers can be offset by the reduction in electricity costs and possible additional arrangement with the utility.

1.1.3 Vehicle Owner

There are only two interests for the vehicle owner and they are conflicting. On the one hand, the vehicle owner could profit from every kWh of electricity that is discharged from the ESS to the utility/building owner. However, each cycle of the battery will contribute to battery degradation and will reduce the useful vehicle propulsion lifetime of the battery. The rate of degradation will be of utmost concern because battery replacement is expected to be extremely expensive for the foreseeable future. The vehicle owner should have no preference for V2G or V2B, and only will be concerned with the price per kWh difference of electricity for charging (which will be desirable to the vehicle owner for the home commute) and discharging in comparison to the capital costs of replacing the ESS from the increased usage. It should be noted that the degradation rate is a concern for batteries only. With significant advances in ultra-capacitor technology (such that these solid-state electricity storage devices are employed in PHEVs and EVs), the degradation rate will be of much less concern and the vehicle owner may be much more inclined to participate in V2G and V2B applications.

2. STUDY METHODOLOGY

The methodology of this study is to use the accumulated data from the power and energy demand study to develop scenarios for realistic V2G and V2B schemes. The scenarios are simplistic, with only single charge and discharge bi-directional events. The APS TOU rates are used to estimate the costs and benefits to the three stakeholders of the V2G and V2B functionality. The rates used are the summer peak rates, which are higher than those for the rest of the year, making the estimate a slight exaggeration. However, there already is an industry push to move toward highly differentiated TOU rates, and the implementation of V2G and V2B schemes is further motivation, making this assumption reasonable. The derived estimates are not comprehensive. For example, it is outside the scope of this study to attempt to quantify the benefits of the ability to store the electrical energy from intermittent renewable sources to a utility. The estimates are extrapolated for an entire year by assuming 20 business days per month on average for the 12 months, for a total number of 240 business days. The potential additional costs due to power demand charges (i.e., where a utility charges a [usually commercial] customer for exceeding a certain threshold of power during a billing cycle) were not included in this study. These demand charges were not considered in the experimental implementation of the bi-directional charging; therefore, the impact was not considered for this modeling exercise. Furthermore, demand charge concerns potentially can be alleviated by adding ground energy storage.

To develop the charging protocol, the Nissan LEAF™ was used as the model vehicle for both the V2G and V2B scenarios because of the large capacity of its ESS. The site experimental data include bi-directional charging of a Hymotion Prius PHEV. Because of the relatively small ESS contained by the experimental PHEV, for this type of charging to be feasible, more bi-directional chargers would be required to achieve adequate energy storage and peak demand reduction. This might prove capital cost prohibitive. Therefore, the proposed charging protocols were not validated using the Hymotion Prius PHEV. The Nissan LEAF ESS has a capacity of 24 kWh and the vehicle is expected to consume 240 Wh/mile when operating in the Urban Dynamometer Driving Schedule (UDDS).

2.1 Site Power Demand Data

Figure 1 shows the base site meter load for the experimental site building during a typical day (March 2, 2010). This site meter covers a warehouse and was selected to avoid any unnecessary interruption of the main building. The power demand of this site meter is less than 4.2 kW alternating current (AC). The spikes in the chart occur when the air conditioner turns on.

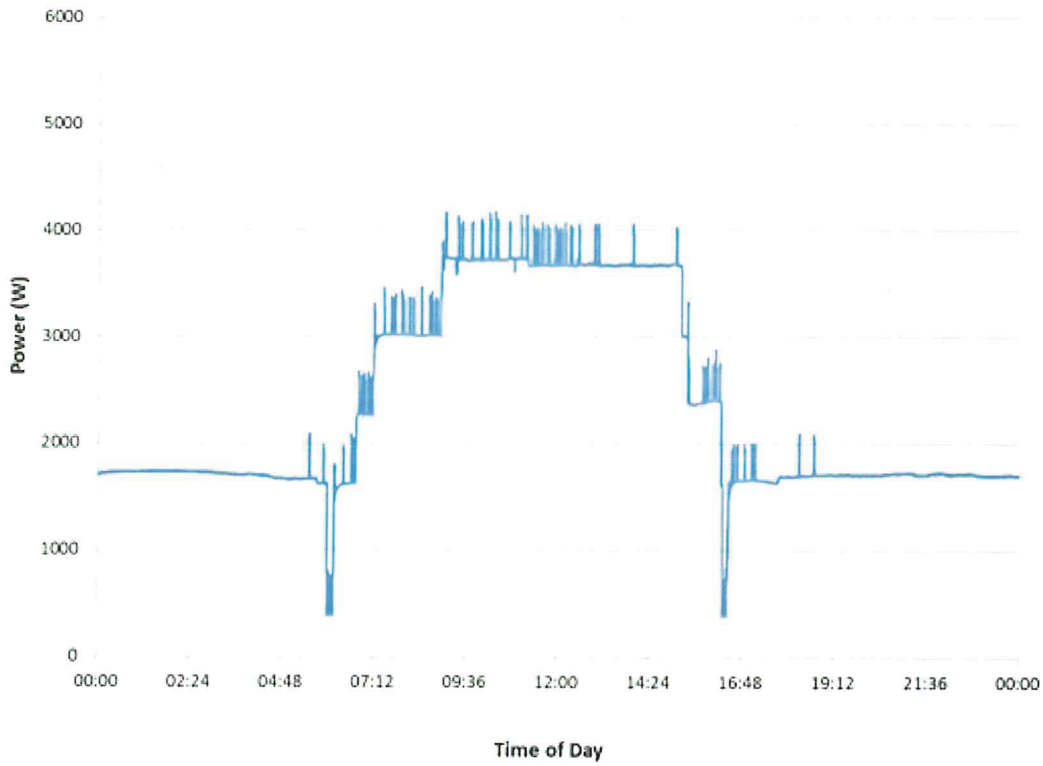

Figure 1. Base site meter power load profile.

APS considers the on-peak hours to span from 11:00 a.m. to 9:00 p.m., Monday through Friday, with off-peak hours assigned to the rest of the day. By integrating Figure 1, the energy demands covered by the site meter can be calculated.

- Daily electricity consumed: 51.7 kWh
  - On-peak total: 23.9 kWh
  - Off-peak total: 27.8 kWh.

The base site meter load data collected in the power and energy demand study were used in two scenarios devised to exhibit the costs and benefits of the V2G and V2B systems. The charge/discharge profiles were developed, as discussed in the following section.

2.2 Arizona Public Service Commercial Electricity Rates

The TOU rate schedule for a commercial APS customer with peak demand below 20 kW per month is presented in Table 1. The difference in price between the on and off-peak rates is surprisingly small at $0.04393 per kWh for the first 5,000 kWh and $0.03859 per kWh for all energy demand over 5,000 kWh. It should be noted that the cost of electricity for APS commercial customers is based on both energy and peak power; however, the classification with the lowest peak power has the highest tariffs. The peak power thresholds that separate the classifications will have important implications for V2G and V2B applications, as discussed in the concluding section of this document.

Table 1. Arizona Public Service commercial rates for small-scale facility.

May through October Billing Cycles (Summer)	Cost per kWh	November through April Billing Cycles (Winter)	Cost per kWh
First 5,000 on-peak kWh	$0.16831	First 5,000 on-peak kWh	$0.15082
On-peak kWh over 5,000 kWh	$0.08318	On-peak kWh over 5,000 kWh	$0.06565
First 5,000 off-peak kWh	$0.12438	First 5,000 off-peak kWh	$0.10686
Off-peak kWh over 5,000 kWh	$0.04459	Off-peak kWh over 5,000 kWh	$0.03181

The TOU electricity rates are significantly different for APS residential customers. The rates for residential customers increased sharply for the summer peak timeframe in 2009 to include a so-called "super-peak" schedule (Table 2). In this case, the differences between on-peak and super-peak rates are $0.19191 per kWh and $0.44191 per kWh, respectively. These large disparities would drastically change the attractiveness of V2G and V2B if similar rate differences were implemented for APS commercial customers. In particular, the devised charge/discharge algorithms ideally would make use of the super-peak rate for the largest economic gain.

Table 2. Arizona Public Service residential electricity rates for summer peak months.

June through August Billing Cycles (Summer Peak)	Cost per kWh
On-peak kWh used (Monday through Friday, 12 p.m. to 3 p.m. and 6 to 7 p.m.)	$0.24445
Super-peak kWh used (Monday through Friday, 3 to 6 p.m.)	$0.49445
Off-peak kWh used (Monday through Friday, 7 p.m. to 12 p.m. and all day Saturday and Sunday, 6 holidays)	$0.05254

2.3 Vehicle to Grid Scenario

The V2G scenario includes a commute to and from the business from the vehicle owner's home (each direction assumed to be two UDDS cycles for a trip distance of 15 miles), with one charging event (off-peak) and one discharging event (on-peak) at the business building site, as well as overnight charging at the vehicle owner's home (Figure 2). The sequence of charging and discharging the ESS is shown in Table 3, and the off-peak charge and on-peak discharge are superimposed on the existing site data to present the effect of the chosen charge/discharge profile on the site electricity consumption. The data from Table 3 will be used to calculate the various costs and benefits for the three stakeholders in the V2G system. It should be noted that both scenarios assume a vehicle owner with no "range anxiety" because the commute home is begun with an ESS state of charge (SOC) of 50%. This might not be feasible for EV owners, as discussed in the conclusions.

Table 3. Vehicle to grid scenario sequence.

Time	Description	ESS SOC Change	DC Energy
7:30 to 8:00 a.m.	To-work commute, two UDDS cycles	100%→85%	3.6 kWh
9:00 to 11:00 a.m.	Off-peak charge at business site, 1.8 kW direct current (DC)	85%→100%	3.6 kWh
3:00 to 4:40 p.m.	On-peak discharge at business site, 7.2 kW DC	100%→50%	12.0 kWh
5:00 to 5:30 p.m.	To-home commute, two UDDS cycles	50%→35%	3.6 kWh
5:00 p.m. to 7:30 a.m.	Overnight charge at vehicle owner's home	35%→100%	15.6 kWh

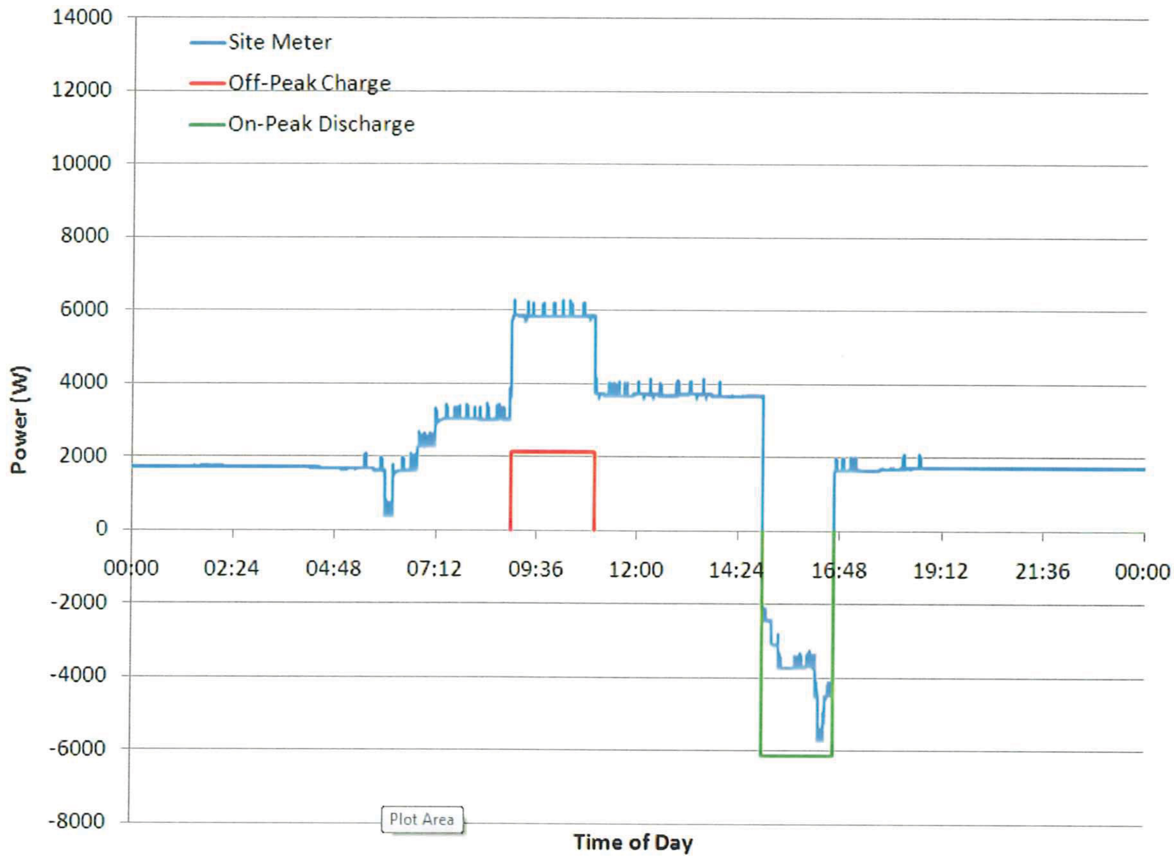

Figure 2. Vehicle to grid scenario power profiles.

The peak hours begin at 11:00 a.m., and with a charge event that occurs prior to this time and spans two hours (from 9:00 to 11:00 a.m.), the vehicle can be charged at a relatively lower rate (1.8 kW) to replenish the consumed 15% capacity during the morning drive. This relatively lower rate should be controlled case-by-case to ensure that excess building power demand charges are not trigged. The discharge power level was assumed at 7.2 kW DC power and occurs between 3:00 and 4:40 p.m. to coincide with the super-peak residential period. The discharge results in 12 kWh DC energy (10.2 kWh AC) extracted from the vehicle battery that offsets the building energy demand during this discharge event (3.6 kWh AC) and sends a portion (6.6 kWh AC) to the grid. This discharge rate should be limited by battery tolerance and potentially the demand from the grid.

With an assumed AC/DC conversion efficiency of 15%, the site energy characteristics for the V2G scenario include the following:

- The overall site AC energy demand for the V2G scenario day is 45.7 kWh
  - On-peak: 13.7 kWh
  - Off-peak: 32.0 kWh.
- The off-peak AC electricity required from the business building for the charge event is 4.2 kWh.
- The on-peak AC electricity acquired from the vehicle during the discharge event is 10.2 kWh, wherein
  - The amount of net energy that could potentially be sold back to utility is 6.6 kWh AC.
  - The amount of building energy that is avoided by the discharge event is 3.6 kWh AC.

2.4 Vehicle to Building Scenario

The V2B scenario is slightly different from the V2G scenario. The commutes and off-peak charge event are the same, but the length and power level of the on-peak discharge event is modified to ensure that the discharge power is never greater than the overall site power, which is approximately 4.0-kW AC power for the study case. The purpose of V2B is to reduce as much of the building on-peak energy consumption as possible; therefore, a lower power level over an elongated period of time is used and no power is sent to the grid. As shown in the V2B scenario sequence of Table 4, the discharge power level was set to be 4.0 kW DC power instead of 7.2 kW as in the V2G scenario. The charge and discharge events are shown (at AC power levels) superimposed on the site power profile in Figure 3.

Table 4. Vehicle to building scenario sequence.

Time	Description	ESS SOC Change	DC Energy
7:30 to 8:00 a.m.	To-work commute, two UDDS cycles	100%→85%	3.6 kWh
9:00 to 11:00 a.m.	Off-peak charge at business site, 1.8 kW DC	85%→100%	3.6 kWh
12:00 to 3:00 p.m.	On-peak discharge at business site, 4.0 kW DC	100%→50%	12 kWh
5:00 to 5:30 p.m.	To-home commute, two UDDS cycles	50%→35%	3.6 kWh
5:00 p.m. to 7:30 a.m.	Overnight charge at driver's home	35%→100%	15.6 kWh

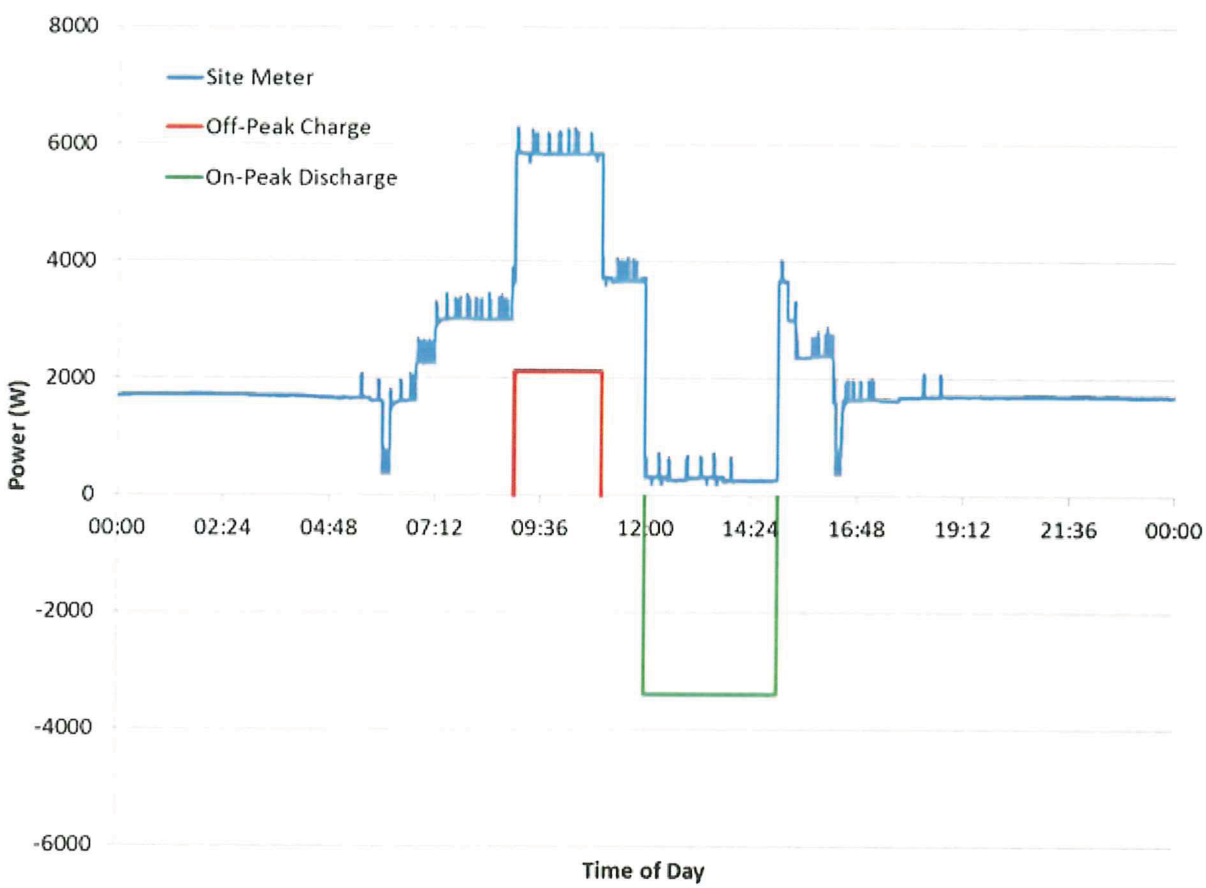

Figure 3. Vehicle to building scenario power profiles.

The energy demand profile for the V2B scenario day is the same as for the V2G scenario, although the power profile is different. No net AC electrical energy is sent to the grid for the V2B scenario. The lower power level (4.0 kW versus 7.2 kW) of the battery discharge may cause less degradation to the ESS, as discussed in Section 3.3.

The site energy characteristics for the V2B scenario include the following:

- The overall site AC energy demand for the V2G scenario day is 45.7 kWh:
  - On-peak: 13.7 kWh
  - Off-peak: 32.0 kWh.
- The off-peak AC electricity required from the business building for the charge event is 4.2 kWh.
- The on-peak AC electricity acquired from the vehicle during the discharge event is 10.2 kWh; all of this energy is used to offset building energy usage.

3. ANALYSIS

The V2G and V2B scenarios are compared with the base case where no charge events occur. As stated in Section 2.1, there are 27.8 kWh of electricity consumed in the base case during off-peak time and 23.9 kWh during on-peak time. Using the rates listed in Table 1, the electricity cost is $3.46 (off-peak) and $4.02 (on-peak) for a total of $7.48. Extrapolated over 240 business days, the utility income for this facility would be $1,795.32.

3.1 Utility Benefit Analysis

For the V2G scenario, 3.6 kWh of on-peak electricity are not consumed (during the discharge event versus the base case) and 4.2 kWh more off-peak electricity is consumed (during the charge event versus the base case) by the building. This leads to a $19.71 loss in direct income for the utility from the electricity usage of the business building due to the net electricity gain from the charge/discharge events throughout the year. Even so, the V2G case allows for 6.6 kWh of on-peak electricity to be sold to the grid. If the utility is willing to buy this electricity at the on-peak commercial rate ($0.1244), either from the business building owner or vehicle owner and is able to sell it at the super-peak residential rate ($0.4945), the utility could see an overall net annual gain of $785.58 over an entire year for the electricity at the business building. At the same time, the utility will gain $105.92 from the additional charging energy (8.4 kWh) that the vehicle owner must obtain at home in order to accommodate the charge/discharge events. With these, for V2G cases, the utility is seeing a profit increase of $872.27 (49%) over the base-case income. This benefit presumably takes into consideration (at least in part) the operating cost reductions for the utility if it does not need to start up a peaking plant because of the energy acquired from the vehicle. However, the benefits of storage of intermittent renewable energy are not considered here.

For the V2B scenario, 10.2 kWh of on-peak electricity are not consumed (during the discharge event versus the base case) and 4.2 kWh more off-peak electricity is consumed (during the charge event versus the base case) by the building. This leads to a $286.65 loss in direct income for the utility from the electricity usage of the business building due to the net building electricity usage reduction from the charge/discharge events throughout the year. At the same time, the utility will gain, in the same way as for V2G, $105.92 from the additional charging energy (8.4 kWh) that the vehicle owner must obtain at home in order to accommodate the charge/discharge events. In this V2B scenario, the utility sees an overall net loss of $180.73 per year, which is a 10% loss. There is no electricity sold to the grid in the V2B scenario. However, the utility can still take advantage of the reduction in electricity usage at this particular site by sending the power to other customers, notably residential customers.

Tables 5 and 6 show the differences in energy consumed for the V2G, V2B, and base case and the comparison of utility benefits (i.e., dollar gains) among these cases. In the base case, the yearly income is $1,795.29.

Table 5. Energy usage of business building.

	Base (kWh)	V2G/V2B (kWh)	Charge Events (kWh)	Electrical Cost ($)
On-peak	23.9	13.7	-10.2	($412.02)
Off-peak	27.8	32.0	4.2	$125.38
Net electricity sent to grid (kWh)		V2G scenario	6.6	$785.58
		V2B scenario	0	–

Table 6. Comparison of utility benefits for vehicle to grid and vehicle to building scenarios versus base case.

	V2G		V2B	
	Gain	Percentage Gain	Gain	Percentage Gain
Annual loss from business	$19.24	1%	$286.65	16%
Annual gain from residential	$105.92	–	$105.92	–
Potential gain from V2G	$785.58	–	NA	–
Potential net gain (maximum)	$872.27	49%	($180.73)	-10%

For the utility, these values would likely be even more favorable when the actual costs of peak power plant operation and the ability to make use of intermittent renewable energy sources are considered. Depending on the actual cost of providing peak power and supposing that the peak rate of Table 1 does not cover these costs, the utility will likely benefit from the reduced demand that the V2B functionality will allow. However, the value-added proposition of storing energy from intermittent renewable energy sources is unavailable in the V2B scheme.

In addition, a V2G scheme also could be implemented without using the building as a conduit; the off-board vehicle charger could be connected directly to the grid. The bi-directional charger would require circuit protection similar to what the building provides, but this would provide the utility with more control of the electricity sent to the grid, because the building power demand would not be a factor.

3.2 Building Owner Benefit Analysis

For the V2G scenario, the building owner will pay the utility when the building power demand is positive and will receive income from the utility when the building power demand is negative. As shown above, the cost of electricity for the building owner will be $19.24, which is 1% less than in the base case for the entire year. The building owner would see no other benefit and would not have control over when the charging and discharging would occur. This could result in a suboptimal situation for the building owner, who could otherwise time the charge/discharge events to minimize the building electricity usage costs.

For the V2B scenario, the value of the discharge energy would be subtracted from the building owner's monthly power bill; with no periods of negative building power demand, no electricity is sent to the grid. The building owner will see a bill reduction of $286.65, which is 16% less than in the base case and will have more control over the timing of the charge and discharge events if the power demand profile differs from the example scenarios.

3.3 Vehicle Owner Benefit Analysis

The situation will be the same for the vehicle owner for either V2G or V2B, except that in the scenarios used in this study, the power of the V2B discharge event is lower, meaning that less degradation of the ESS will occur. For both scenarios, the vehicle owner must consume 9.9 kWh AC power every night in a home charge event to compensate for the building usage. With a rate of $0.0525 for residential off peak rate, the vehicle owner would pay an additional $124.61 per year to participate in the V2G or V2B implementation. However, the vehicle owner will want to be compensated for the degradation this extra use will inflict on the ESS. In order to estimate the level of compensation, the cost for replacement and rate of degradation must be determined. The current estimated cost of the Nissan LEAF ESS is $375/kWh for a $9,000 total, while the goal of the United States Advanced Battery Consortium for long-term commercialization of ESSs is $100/kWh. The current capability of Li-ion technology is approximately 1,000 cycles.

In calculating the degradation effects of battery cycles, it is assumed that partial discharges can be added linearly to obtain full cycles. For both scenarios, discharges cause an additional full cycle to be added to the ESS history (from the 50% discharge and the portion of the 65% overnight charge that would not occur without the discharge) for each business day. This means that the added burden of supplying electrical energy to the grid or building will mean that even if there is no other usage of the ESS, it will have to be replaced after 4.2 years. The driving, overnight charging (only the portion that occurs because of the commute), and off-peak charging at the building will add 144 cycles to the ESS history per year. This alone requires the ESS to be replaced after 6.9 years. The V2G and V2B schemes will reduce the latter replacement timeframe to 2.6 years. Because these schemes are not close to commercial implementation, the goal of the United States Advanced Battery Consortium of $100/kWh will be used for the economic evaluation. Using a time-value-of-money calculation and assuming an interest rate of 3% and a future value of $2,400 (the future cost of ESS replacement), the present value is $2,222. Over the period of 2.6 years, a net 3,744 kWh will be extracted, meaning that the vehicle owner would want compensation of at least $0.59 per kWh. It should be noted that based on the relatively small energy demand of the commute, the vehicle owner would likely not be open to paying for the off-peak charge event, meaning that this electricity cost would have to be borne by either the utility or building owner.

4. CONCLUSIONS

A V2G scheme could be beneficial to the utility, especially if it can redistribute and resell the electricity saved by the business site to other end users. Other potential benefits come from the value in reduction of peak energy demand, potentially forgoing the need to turn on a peaking plant or even build one at all, and the ability to store intermittent renewable energy. V2B is especially attractive to a utility if the difference between on and off-peak rates is very large but can be useful in allowing peaking plant electricity to be used elsewhere. Of the two, this analysis shows that the V2G option would likely be preferable to the utility, because it allows for more control of the ESS and provides electricity at the time of the utility's greatest need and not simply at a time that reduces the overall electricity bill of the building.

The V2G situation is of only marginal value to the business owner in the current cost scheme. In order to make V2G attractive to the business owner, the latter would have to share in the profits of the utility from the sale of the super-peak power. Alternatively, the building owner could be compensated by some other means, such as receiving free charging stations for employee use. These stations could be used by the building owner as a perk for employees, thereby increasing the attractiveness of the business as a place of work. The V2B situation is very favorable to the business owner because the direct electrical costs are lowered in a controllable manner. The V2B situation may still be attractive enough to the utility for the business owner to charge for the reduction in energy; this analysis will vary and must be negotiated between the stakeholders.

The compensation that the vehicle owner would require and the current structure of the TOU rates of APS means that both V2G and V2B schemes would be beneficial to the building owner simply because the on-peak energy demand would be reduced. For the building owner, the rate structure is of paramount importance because there is no benefit from not having to bring peaking plants online or having the ability to store electricity from intermittent renewable sources.

The vehicle owner would require compensation ($0.59 per kWh) in order to not lose money on the proposition (because of ESS replacement). With the current structure of the super-peak TOU rate of APS ($0.4945 per kWh), the schemes currently are not economically feasible. The vehicle owner must have ultimate control over usage of the ESS. In this study, the vehicle owner allows the ESS to be discharged to 50% SOC because the commute home is sufficiently short that the minimum SOC is not reached. However, in reality, the vehicle owner will likely want a fully charged ESS for the commute home. This requirement would mean that there would be no net energy demand reduction for the building. In this case, with the current APS TOU rate, the building owner would see only a net increase in the monthly power bill due to the off-peak vehicle charge (unless a separate agreement is negotiated with the utility). If other TOU rates are introduced, such as the APS rates for residential customers that include the "super peak," the building owner could see a direct monetary benefit by shifting peak loads to less costly rate periods. For the no net energy demand reduction case, the utility would still benefit from electricity storage from intermittent renewable energy sources and flexibility in meeting the power demand and would actually see a direct increase in revenue (outside of a separate agreement with the building owner and vehicle owner) because the off-peak charge would not be offset by the on-peak discharge.

This study is based on the assumption that vehicle owner, utility, and business building owner are three independent identities. If either utility or business building is actually the vehicle owner, the situation of using vehicle battery as energy storage means would be much more flexible and may make the bi-directional concept easier to achieve.

It should be noted that the capital costs of chargers and their installation are not included in this analysis. These costs certainly will not be negligible. Also, there is a trade-off between additional chargers (and the associated costs) and larger energy extractions from the vehicles' ESSs (and higher rates of degradation and replacement) that would need to be optimized. The value to the utility of electrical storage from intermittent renewable energy sources also should be investigated carefully. As the smart grid grows and more chargers are installed with vehicle ESSs to provide storage, the ideal situation would be a V2G scheme with multiple charge/discharge activities for each ESS controlled by the utility, in order to provide storage for intermittent renewable energy and reduce the need for peaking power plants.