Solar-2-Vehicle Project Annual Report, 12/2012 - 12/2013

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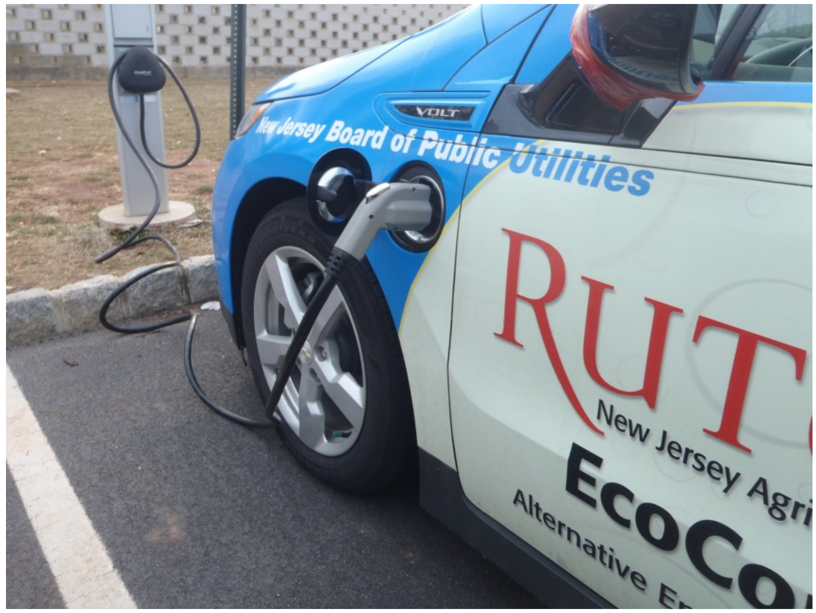
Solar-2-Vehicle Project

Annual Report
12/2012 – 12/2013

Dunbar P. Birnie, III

February 26, 2014



Executive Summary

The Solar-2-Vehicle project began in December 2012 under the auspices of the Rutgers Energy Institute using Rutgers electricity, existing infrastructure and a plug-in vehicle provided by the Rutgers EcoComplex. It was proposed to operate the vehicle in a typical commuter mode limited to work-place charging during daylight hours as a tie-in to the solar-power being generated on campus by the two large Livingston campus arrays. This routine was carried out and data were logged on electricity and gasoline usage as well as the practical availability of the parking spaces where the charging stations were installed. In the process of logging these data more has been learned about the range limits of vehicles and how to project their efficiency in the workplace-only charging scenario. In addition, this project has provided outreach to the EV and alternative fuel community in the region and highlighted unique capability existing at Rutgers in the EV-engineering area. The data collected and the quantitative interpretations are presented below.

Sponsored by the Rutgers Energy Institute and the Rutgers EcoComplex. Additional support from the McLaren Endowment is greatly appreciated.

Background publications of potential additional interest:

- D. P. Birnie, III, “Solar-to-Vehicle (S2V) Systems for Powering Commuters of the Future”, Journal of Power Sources, **186**, 539-542 (2009). (DOI: 10.1016/j.jpowsour.2008.09.118). Also, pre-publication final manuscript archived at RUCore: http://dx.doi.org/doi:10.7282/T3QJ7FF0
- B. D. Viezbicke and D. P. Birnie, III, “Understanding Parasitic Energy Costs for PHEV Conversion Packs as we Move toward V2G”, International Journal of Electric and Hybrid Vehicles, **3**, 309-317 (2011). (DOI:10.1504/IJEHV.2011.044386)

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Results

This project was initiated with the intention of testing a specific commuter operating mode for the plug-in vehicles in connection with work-place solar power. In addition, it was hoped that this would highlight the importance of solar power installations as parking lot canopies and that other incidental data would be gleaned from the usage patterns and observations. This report provides a complete analysis of these different angles. First, the basic distances and energy usages for the travel that was conducted during this year are presented. Then, specific characteristics of the vehicle being used are presented. And, data on the utilization of the main plug-in spots on campus are then analyzed, especially in terms of assessing congestion and providing comments on strategies for placement of future plug-in equipment. Finally, other observations are made of the community of EV users that were active during the test period.

The comprehensive testing commenced on December 13th, 2012 and all travel information was logged during regular commuting and other business travel during the complete following year. Data logged included time of day, external temperature, dashboard console information on mileage, power, and gasoline usage[1]. In addition, data were maintained on location of plug-in power used as well as to log the various other users of the plug-in spots on campus. Further, the system data from the charging stations (through ChargePoint and Blink) were gathered at intervals to understand usage patterns and amounts of energy provided by the

[1] Note that the vehicle in question was a 2012 Chevrolet Volt. No endorsement is implied; this was simply the vehicle at hand and was kindly loaned by the Rutgers EcoComplex. The Chevy Volt has a powertrain that is entirely electric and a battery capacity of 16 KWH (nominal). In addition, its standard configuration has a gasoline powered electric generator, so even when the battery has been drained the vehicle still has sizeable range, though traveling on gasoline. Generally, the vehicle power system uses electricity first, though in cold weather it cycles back and forth between gas and electric to protect the battery from abuse. This operation is beyond the control of the driver.

Rutgers grid. These data were digested to provide the various conclusions here and in the following sections.

In total during the test 7809.0 miles of travel was logged. During this year then 6197.5 of the miles were under battery-electric mode (79.4%), while the remaining 1611.5 miles were under gas-generator-powered mode (20.6%). For this travel then 1979 KWH of electricity was provided from the Rutgers grid and 44.9 gallons of gasoline were consumed. If we compare the travel under all-electric mode with the electricity that has been provided by charging then we can get a composite number for the electric-drive efficiency at 3.13 miles per KWH, averaging through the year. **Figure 1** shows how the electric drive efficiency evolved through the test-year with each data point derived from each battery refill event. Likewise using the gas-powered datapoints we find an average of 35.9 miles per gallon, as shown in **Figure 2**. Since the gasoline usage was often small or even zero then it wasn't possible to evaluate this ratio on a seasonal basis, but it is expected to be similar.

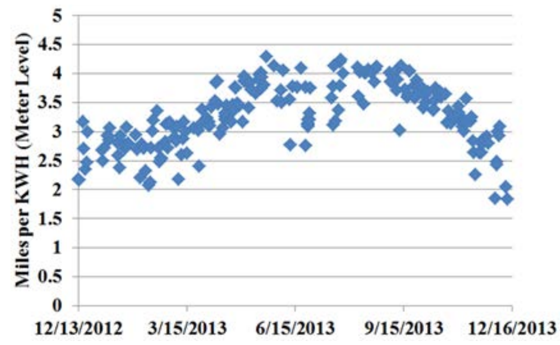

Figure 1: Miles traveled per KWH of energy metered at grid source level, through the year 1 testing period.

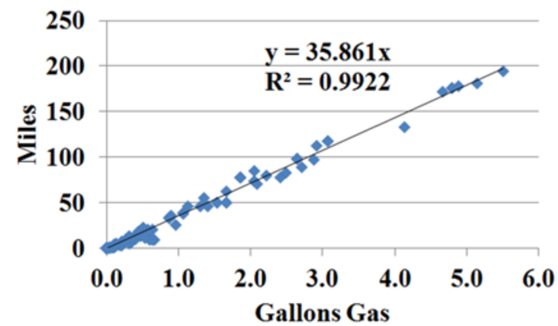

Figure 2: Miles traveled as a function of the quantity of gasoline used. The least-squares slope gives the miles-per-gallon rating for this vehicle.

Detailed Vehicle Performance Stats

As shown before in **Figure 1** there is a significant change in the electric-drive efficiency throughout the seasons, with the efficiency being notably lower in the winter and generally much better in the summer. Part of this can be attributed to the battery being at a different temperature and possibly influencing the charge/discharge kinetics. On the other hand, there were other major seasonal power needs in the car: window defrosting in the winter, heating and AC under extreme conditions, and headlights for nighttime travel (more frequent in winter). Since these various uses of energy weren't metered separately then it is not possible to pin down exactly the sources of the seasonal differences.

The average electric-drive efficiency found above was 3.13 miles per KWH based on the electricity metered in. However, as this power was only used after being stored in the battery we are able to assess this "round-trip" storage efficiency. **Figure 3** shows a comparison of the energy received from the meter (X-axis) and the energy metered out of the battery during

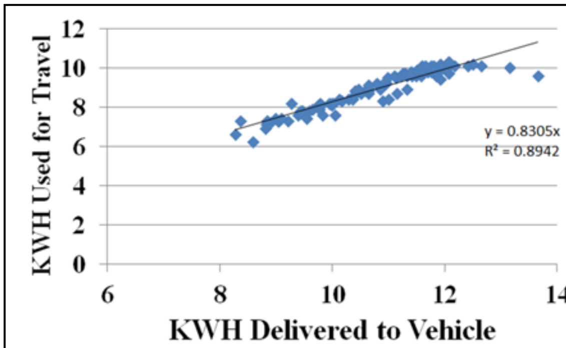

Figure 3: Round-trip electric energy recovery after storage in the vehicle battery.

use and logged on the dashboard/console (Y-axis) for each battery recharge event through the test period. Assuming a simple linear relationship then we derive an 83% round-trip efficiency for the charge/discharge process, averaging through the whole year. It is interesting to note that this round-trip energy recovery ratio also changed with season, as shown in **Figure 4**. The best values were typically found during the colder seasons, suggesting that the relatively complicated battery temperature management system[2] may add parasitic power losses that don't get logged at the dashboard level especially during the warmer parts of the year when active cooling may be needed.

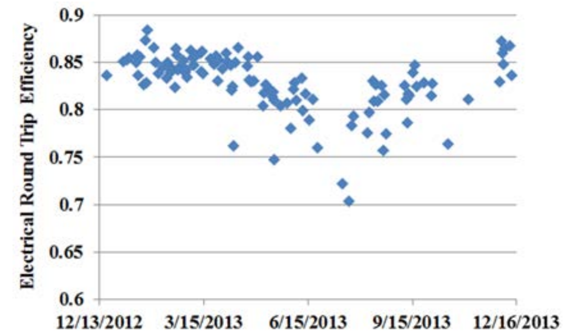

Figure 4: Seasonal variation of the electrical round-trip efficiency.

This vehicle-level energy usage information is used by the vehicle to project the travel range that is remaining and constantly provides this information to the driver on the dashboard in real time. This "EV range" is likely calculated on the recent weeks of travel and therefore inherently takes into consideration the two competing effects: (1) in the summer the net miles traveled per metered-KWH is much higher than in the winter (shown before as **Figure 1**) but that (2) in the summer the round-trip electrical efficiency is lower (shown in **Figure 4**). This seasonal variation of the EV range is shown in **Figure 5**. These data vary dramatically from winter to summer, again according to the many factors discussed above. A sampling of summertime data points fall relatively far below the generally-smoothly-varying seasonal changes; these are thought to be from relatively hotter parts of summer, where more AC was needed for driver survival.

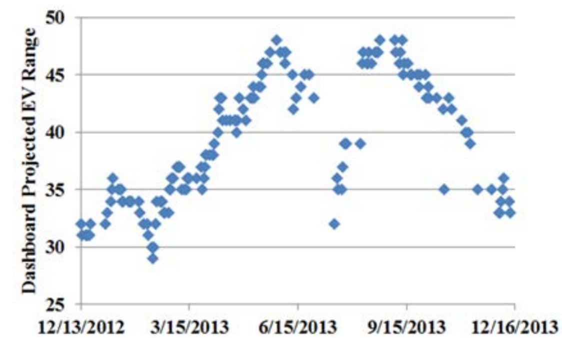

Figure 5: Vehicle's projected range logged at each battery refill event during test period.

Solar-2-Vehicle Commuter Concept Testing

The EV Range and its practical utilization for basic commuting was the core concept for this year of testing. The project was aimed specifically at demonstrating that under some circumstances it would be possible to be a commuter who was able to utilize solar-generated workplace parking/charging locations to feed full round-trip commuting. Similarly this could equally well demonstrate the converse model: full-electric commuting sourced at home from grid-available electricity (and for most commuters this would likely be taken at night). In either case the times, distances, and traffic conditions would be the same. **Figure 6** shows the final performance metrics related to the core hypothesis. For this plot a 40 mile distance was used as the cutoff for consideration. Clearly a majority of the

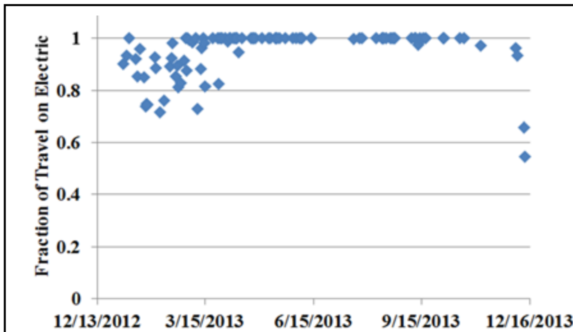

Figure 6: Fraction of simple round-trip commute cycles powered completely on electricity.

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[2] Extensive information about the vehicle and battery system can be found at http://gm-volt.com.

trips have been conducted entirely on electricity, but in the colder seasons then there are many instances of commute cycles that required some gasoline after the EV range was exhausted.

Infrastructure Utilization and Observations

Now we turn our attention to the charging characteristics of the combined set of users and of the equipment installed at Rutgers by the CAIT building on Busch Campus. These units (often abbreviated EVSE, for Electric Vehicle Supply Equipment) are dual service units each have one level-2 plug and the ability to charge at Level-1 by plugging into an outlet (**see Figure 7**). Because of the availability of two simultaneous plug modes then the pair of units were installed in front of four adjacent parking spaces, as shown in **Figure 8**.

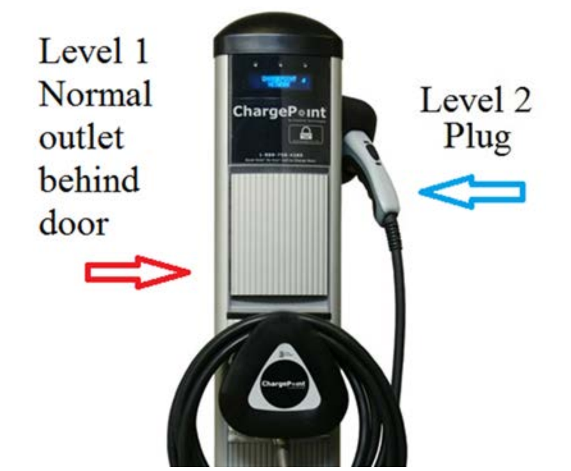

Figure 7: ChargePoint units of the type installed by CAIT on Busch Campus. These provide simultaneous Level 1 and Level 2 charging if needed. Most users prefer to plug in at level 2.

Figure 8: Installed locations of the main EVSE used for the present study. Yellow dots give the approximate locations of the dual mode charging stations servicing the four parking spots enclosed.

During the year of testing complete notes have been kept on the occupancy of these four parking spaces and their connection to the charging equipment. While the actual parking spot occupancy was only possible when I was there (arriving, leaving, or moving the vehicle), the connection logs downloaded from the ChargePoint system provided further information about their usage. These data were combined to help provide a more complete picture of the utilization of the EVSE at Rutgers during this past year.

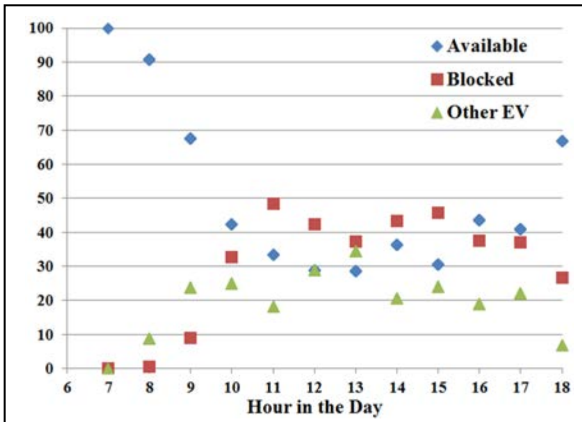

Figure 9: Probability of occupancy as a function of time of day for the CAIT locations. The groupings are rounded down: thus, the 9 O'Clock entry includes all data points through 9:59.

The occupancy data were processed to provide an hour-by-hour overview of the usage of the four spots. To avoid confounding affects caused by measuring my own utilization, the data reported below are based on observations of the remaining parking spots subject to the understanding that I was typically occupying one of the spots already. **Figure 9** shows how the parking space utilization was as a function of time of day, where the data were grouped as: "Available", "Blocked" (meaning occupied by a non-plug-in vehicle), and "Other EV". This chart shows a pattern that would be typical for a university location: basically empty in the early morning, then with people leaving substantially by 6PM. And, we see pretty constant occupancy throughout the day which might be expected for a work-place location where most drivers stay for the majority of the day, though clearly there is some turnover. This shows a pretty steady usage, but the "blocked" fraction is quite significant at around 30-40% for most of the day. On average this is at least one full parking spot prevented from access for most of the day.

It is interesting to see how the usage might have changed during the progress of the one year of study. So taking the samples from the bins covering the most usage, but then grouping them by date instead (into 2-week bins), we get the plot shown in **Figure 10**. It is interesting to see that the usage by EV's has increased significantly during this year (which was also clear by the appearance of new vehicles that hadn't been system users when this study commenced). And, the bigger change with time is the reduction of blocking by non-EV parked cars. While the signage is clear that preference should be given to EV's, there is not specific prohibition and there is no ticketing mandate in effect. However, it seems that the population of non-EV drivers at least has gradually improved at how they preserve these spots for EVs. And, this has happened in tandem with the arrival of more EV's and so these may be helping assist in emphasizing that the EV stations are being used.

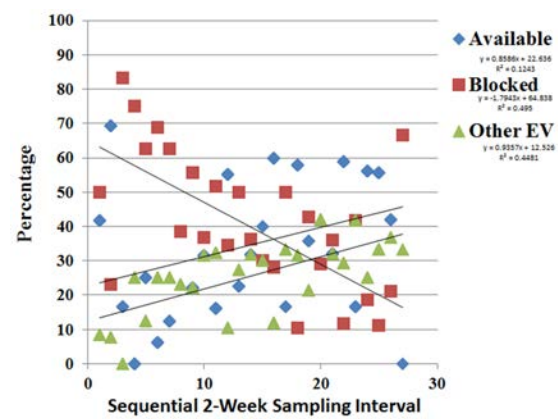

Figure 10: Parking spot congestion mapped through the one-year test period. Other EV usage has increased significantly during this time.

Next we turn attention to the entire population of EV users and their usage patterns. The ChargePoint usage logs provide session information that includes start and stop times, energy delivered (in KWH), power provided (level 1 or level 2) and some other basic stats. One key measure of the usage is the amount of time that the plugs are "in-use" which is a proxy measure for the length of time that the parking space has been occupied. **Figure 11** shows the cumulative probability distribution as a function of the length of time plugged in. Sessions which were shorter than 2 minutes were not included as these were often incorrectly initiated or were restarted immediately after. The distribution shape still has a population of around 10% of sessions that have been between 2 and 10 minutes only (the nearly vertical jog near the origin). After that EV users tend to stay an hour or longer, but the very smoothly linear region from 2 to 6 hours covers about 50% of the sessions. There is a relatively significant grouping at 8-9 hours plug-in time (many of which were plug-in events associated with the present study). The gradual sloping up from 2 to 6 hours might be consistent with

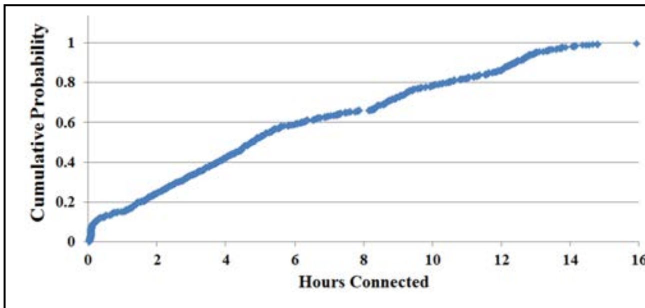

Figure 11: Duration of plug-in sessions plotted as a cumulative probability distribution. Sessions shorter than 2 minutes were not included. The usage is widely and continuously varying including shorter and longer times.

events caused by a full-time employee who needed to attend a meeting on a different location on campus, but returned for continued charging after the interruption. These would likely happen at different enough times that it would give the smooth shape seen.

Because the start and end times are contained in the full session reports then it is possible to identify times when more than one EV was charging – up to the maximum of four that are possible. **Figure 12** shows the daily peak simultaneous usage of the available plug-in spots as a function of time through the year. The fitted line shows a general trend toward more usage consistent with the trend shown above in **Figure 10**. Also, several days were logged when all four spaces were being used simultaneously – both Level 2's and both Level 1's. This happened later in the test year when more vehicles were becoming regular users of the site. Sadly there was a two-month period when one of the Level-2 units was broken (see shaded block). Still in that part of the year there were many days when all three remaining connection spots were simultaneously in-use for some part of the day.

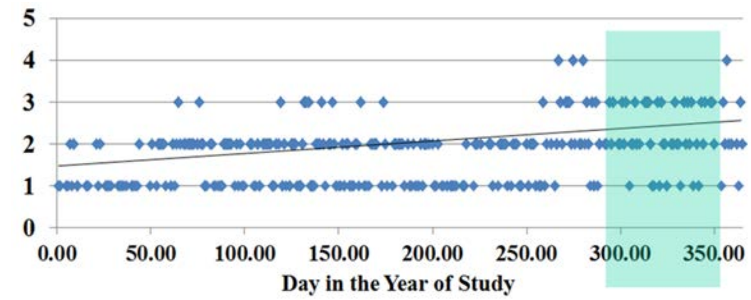

Figure 12: Peak simultaneous usage of the four available plug-in spots. The shaded region covers a time when one of the Level-2 chargers was broken, so the maximum possible during that period was three.

Finally, it was possible to examine the energy delivered and the effective duration of active charging to calculate the energy flow rate (the power) accepted by each vehicle. This was grouped as a cumulative probability distribution, as shown in **Figure 13**. It is not surprising that different vehicle types have different battery management systems and therefore have electronics that control the power usage. Level 1 is limited to 16 amps by the ChargePoint station specifications but likely the current is limited by the vehicles at 12 amps operating at the standard 120 VAC.

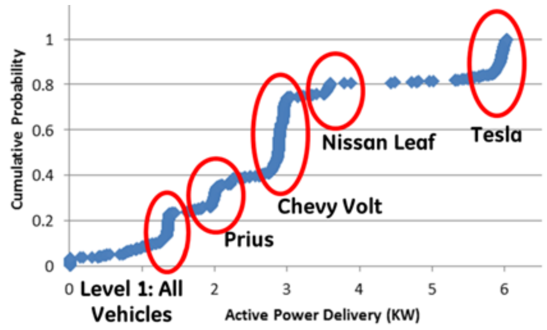

Figure 13: Cumulative probability distribution of the active power provided for each charging session. The specific humps represent vehicle types as marked.

Conclusions

This test-year was successful at evaluating the work-place-charged Solar-electric-powered commuting and much data was collected related to the specific vehicle used as well as the campus charging locations. These data have been analyzed and provide an interesting baseline for developing future EVSE installations on campus. Decisions about location, relative parking congestion, and the options for how future installations might be financed are all interconnected. The present locations have shown a relatively high level of congestion and the EV population of users is rising so this study may help with the planning for future EV users in the surrounding Rutgers region.