

The University as EV Ecosystem Hub

Education and Outreach to Accelerate EV Adoption

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Abstract: The author's university location is being developed as an alternative-fuelled-vehicle "ecosystem" that is serving both educational and research missions. In addition, it is assisting with gradual transition from gasoline-powered private vehicles to PHEV and EV thereby providing real positive regional environmental impacts. By highlighting the early phases of this transformation locally and including students in the discussion we hope to assist in accelerating this transformation for the future. This paper surveys our present status and provides data on the usage patterns as well as on the costs and practical difficulties encountered when considering hardware installation and making site selection.

1 INTRODUCTION

EV's fit into a future where we envision pervasively installed renewable electricity generation (wind and solar) allowing for substantial reduction of fossil fuel usage for transportation. We already see a steep increase in the number of plug-in vehicles on the road, as shown graphically in Figure 1, showing cumulative vehicle sales in the US, with around 10,000 new vehicles being added per month. Still, this has to be considered the "early adopter" phase of this technology transformation. Many of the available vehicles are aimed at higher price points and are commensurate with the early-stage battery costs, though these costs are expected to come down substantially as manufacturing scale is increased.

Another key aspect in this transformation is the infrastructure changes that will also be required to facilitate the practical use of this rapidly growing population of vehicles. This is much more problematic since we are talking about electrical installations at high voltage with many safety and usage considerations.

This technology transformation has begun and should be showcased to students who will be the future technology innovators and civic leaders who will participate in the continuing transformation into the foreseeable future. To provide this educational angle our university has chosen to make our campus location into a visible ecosystem of activity,

involving both educational and research initiatives, and therefore is actively participating in the furtherance of this transformation. The next section surveys the many reasons why EV's must naturally be central to the world's energy usage for the future. Further sections examine how our university's activities can connect into educational, research, infrastructure, and policy themes – all related to the future transportation/energy transformation. Included in this discussion are data measured during the last two years of on-campus EV charging, which provide a baseline for future growth of our ecosystem.

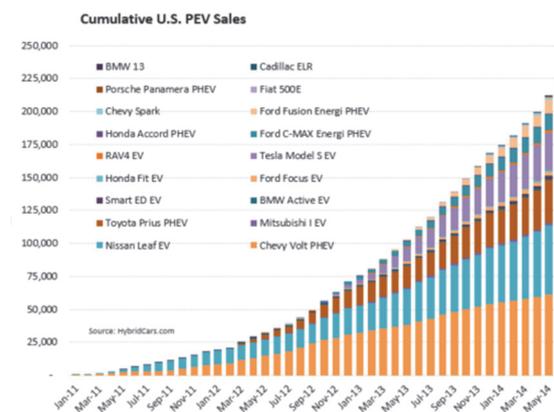


Figure 1: Cumulative US PEV Sales by month showing steady growth beginning in 2012 (EPIC 2014).

The long-term environmental impacts of electrification are bound to improve with time because many regions have regulated utilities where renewable energy generation is mandated (so-called Renewable Portfolio Standards) and so the carbon-footprint per mile will gradually get smaller with the life of the car simply because the grid electricity will be getting cleaner (Anair and Mahmassani 2012) as opposed to gasoline vehicles, which tend to become more polluting with age.

The economics and environmental aspects of plug-in vehicle usage are important topics and cover many situations and issues. Whenever a plug-in vehicle is charging then it is adding to the instantaneous electrical generation requirement from the utility. And, since this is not typically a planned or gradual electrical usage then it must be budgeted against the more rapidly rampable generation sources rather than the base load foundational generation (which are usually not the zero-carbon-footprint renewables like solar and wind). So the time-of-day when vehicles are plugged in has consequences for the cost of electricity generally, and for the ability of the grid to provide the overall need.

In addition to the simple charging aspects of plug-in vehicles, it has been proposed that EV's be used for grid storage – essentially allowing bidirectional charge/discharge usage, a system which is called “Vehicle-to-Grid”, or V2G (Kempton and Letendre 1997; Kempton and Tomic 2005; Tomic and Kempton 2007; Lund and Kempton 2008). Implicit within the V2G concept is the need for fleets of vehicles to be plugged into the charging network for times when not in use for regular driving. This then makes it possible for smart systems to allocate the service instantaneously with optimization aimed at maximizing economic value while preserving comfortable driving range; operation to minimize carbon footprint is also imagined (though no battery system has yet been devised with full 100% round-trip energy retention).

The V2G valuation is increased when the battery size in the vehicle is increased because it becomes possible to buy (at night) and sell (during the day) larger quantities of electricity; and, it is possible with a larger battery to provide a larger power input/output to the grid for frequency regulation. However, it has also been pointed out that these larger batteries also necessitate the use of heavier cars than we might otherwise need – and that driving these heavier cars requires more energy as well – essentially taxing the energy storage buy/sell profits that might be possible when using a

stationary battery (Shiau, Samaras et al. 2009; Viezbicke and Birnie 2011). The optimization of V2G ultimately requires a large population of vehicles plugged-in, infrastructure that is able to monitor and control bidirectional power connection to the grid, and smart algorithms that can reduce overall cost and lower carbon-footprint system wide. This is a classic “chicken-vs-egg” problem balancing vehicle purchase and infrastructure availability. As adoption accelerates we will reach a tipping point where there are enough vehicles connected that this economic model can move forward. Thus, in the near-term we must be examining policies and research efforts that can accelerate the adoption and bring this new transportation reality to fruition.

Our initial step in this direction was aimed at making the connection between workplace solar power generation and daytime-workplace plug-in availability (Birnie 2009). Our “Solar-2-Vehicle” concept thus highlighted that using combined workplace and home charging that battery range limitations are diminished substantially and a greater fraction of travel can be electrically powered (with a lower carbon-footprint per mile travelled). This concept has been substantiated by testing energy usage when trying to maximize the utilization of workplace solar power (Birnie 2014).

With this background, the main campus of Rutgers, The State University of New Jersey, has selected this topic as a strategic initiative – where research, education, and outreach can be combined and will highlight this important technology transformation as it moves forward. As a calibration of our location, Figure 4 shows the one-way driving distance between home and school for a

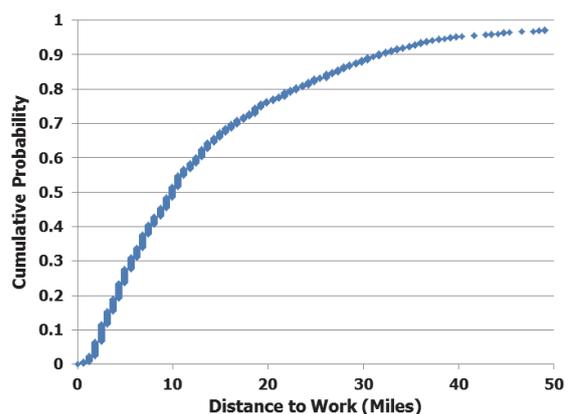


Figure 4: Cumulative probability of travel distance from home to Rutgers campus using over 900 randomly-chosen permit holders. About half of the Rutgers parking population lives within 10 miles of their campus destination.

representative population of parking-permit holders on campus; a one-way travel distance of 10 or 15 miles is easily handled by many current plug-in vehicles in all-electric mode showing that work-place plug-in is a useful stepping stone toward future transportation electrification. The next section presents a closer look at recent usage patterns for the EV infrastructure now available on our campus.

3 ON-CAMPUS USAGE DATA

As noted above, the Solar-2-Vehicle 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 generation. In addition, it was expected 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 section provides a partial analysis of the usage and different energy evaluations that were achieved, to date.

The majority of detailed testing has been conducted using a standard production 2012-Model year Chevy Volt, which was kindly provided for testing by the Rutgers EcoComplex, with further support from the Rutgers Energy Institute (REI). 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). Detailed commuter operation and data logging 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, energy, and gasoline usage. 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 Rutgers grid. These data were digested to provide the various conclusions here and in the following sections.

In total during the first year of testing 7809.0 miles of travel were logged. During this time 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 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 5 shows how the electric drive efficiency evolved through the test-year with each data point derived from each battery fill-up event. Notable reduction in driving range is evident for winter season driving; part of this is due to the energy required for cabin climate control, but part is also likely due to reduction in battery efficiency at colder temperatures. Also, during the hotter parts of the summer there were times of lower efficiency, which again correlated with times where significant air conditioning energy usage was experienced.

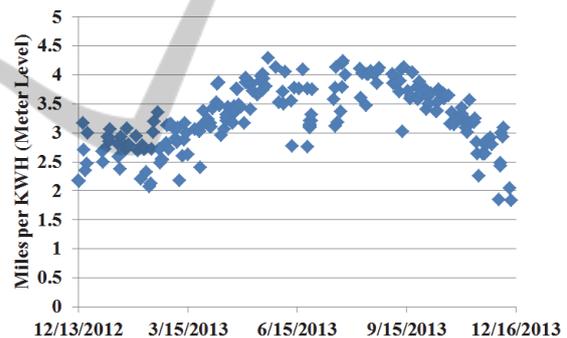


Figure 5: Miles travelled per KWH of energy metered at grid source level, through the year 1 testing period.

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 6 (next page) shows a comparison of the energy received from the meter (X-axis) and the energy metered out of the battery during 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 measure 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; the best values were typically found during the colder seasons, suggesting that the

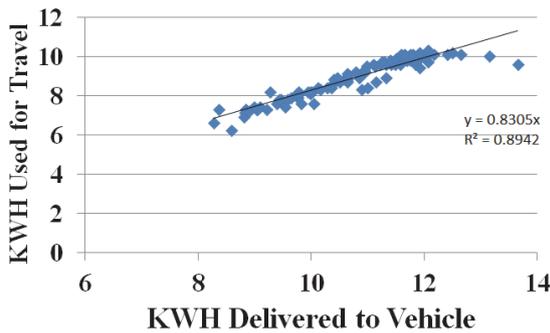


Figure 6: Round-trip electric energy recovery after storage in the vehicle battery.

relatively complicated battery temperature management system may add parasitic energy losses that don't get logged at the dashboard level especially during the warmer parts of the year when active cooling may be needed.

The EV range and its practical utilization for basic commuting was the core concept for that first year of testing. The project was aimed specifically at testing the circumstances where it might be possible to be a commuter who was able to fully utilize solar-generated workplace parking/charging locations to feed full round-trip commuting. Similarly this could equally well substantiate the converse model: full-electric commuting sourced at home from grid-available electricity (which, for most commuters would likely be taken at night). In either case the times, distances, and traffic conditions would be the same. Figure 7 shows the final performance metrics related to the core hypothesis. For this plot a 40 mile distance was used as the cut off. Clearly a majority of the trips have been conducted entirely on electricity, but in the colder seasons there are many instances of commute cycles that required some gasoline after the EV range was exhausted.

During the year of testing complete notes were kept on the *other* users and congestion of the four parking spaces and their connection to the charging

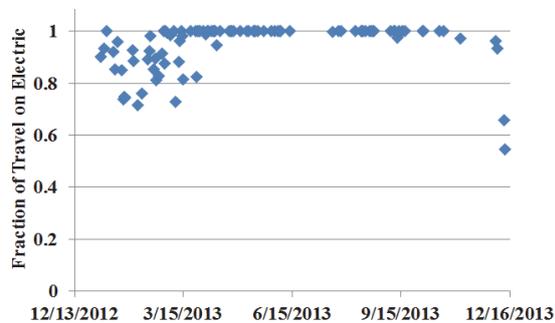


Figure 7: Fraction of simple round-trip commute cycles powered completely by work-place-sourced electricity.

equipment. While the actual parking spot occupancy measurement 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 that full year.

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 8 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

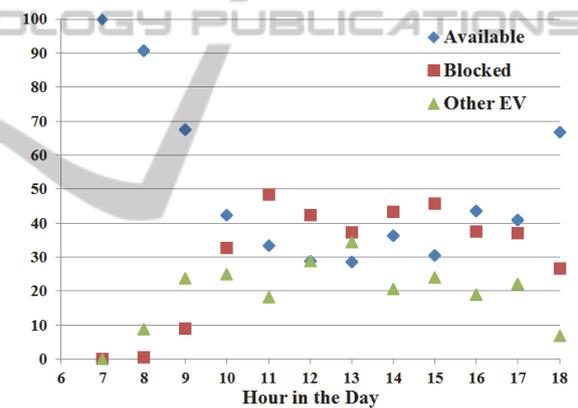


Figure 8: Probability of occupancy as a function of time of day for the EV spots located by the School of Engineering. The time groupings are rounded down: ie, the 9 O'Clock entry includes all data points through 9:59.

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. The parking lot in question was heavily used and during this time period there was no policy in place for preferential usage by vehicles needing to charge and no enforcement, though the signage was clear that they were EV charging spots.

It is interesting to see how the usage changed during the progress of the one year of study. So the data were regrouped into 26 2-week intervals and replotted as Figure 9. It is interesting to see that the usage by EV's increased significantly during this year (which was also clear by the appearance of new vehicles that hadn't been system users when the 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

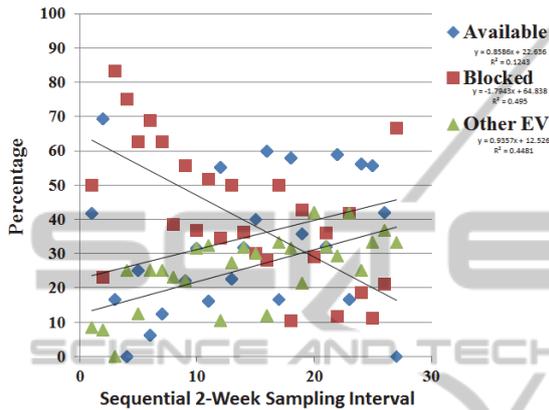


Figure 9: Parking spot congestion mapped through the one-year test period. Other EV usage increased significantly during this time.

should be given to EV's, there is no specific penalty and there has been no enforcement to date. However, it seems that the population of non-EV drivers at least has gradually recognized that there are regular EV users and improved how they preserve these spots for EVs.

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 selected (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 10 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

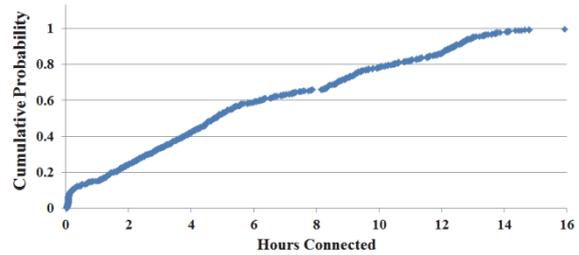


Figure 10: Duration of plug-in session plotted as a cumulative probability distribution. Sessions shorter than 2 minutes were not included. The usage is widely and continuously varying including shorter and longer times.

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 events caused by a full-time employee who needed to attend a meeting on a different location on campus or went out for lunch but returned for continued charging later in the day. These would likely happen at different enough times that it would have combined to give the shape seen.

Finally, we examined the energy delivered and the effective duration of active charging to calculate the power accepted by various vehicles during charging. These data are shown in Figure 11. It is not surprising that different vehicle types have different battery sizes and therefore have electronics that control the power at different levels. The Level 1 specification for our ChargePoint units is limited to 16A but the current seems to be limited by the vehicles at 12A operating at the standard 120V, providing a comfortable safety margin.

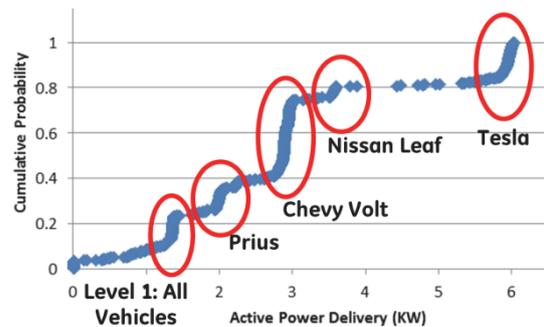


Figure 11: Cumulative probability distribution of the active power provided for each charging session. The specific humps represent vehicle types as marked.

Thus, EV charging data collection and vehicle performance studies can yield a wide range of information about energy systems and the users of these systems. This has added educational benefits when students can participate in these studies, as outlined in the next section.

4 EDUCATIONAL IMPACTS

One key mission of universities is to educate the future generation in their chosen career fields. An equal and commensurate mission of universities is the advancement of new knowledge. Faculty are involved in research on the cutting-edge and students are learning the ropes so they can graduate with the most up-to-date understanding of the world. So universities are natural places to investigate the adoption of new technologies, and in this case, the transformation of transportation from fossil fuels to electricity. It is a huge effort that spans many engineering fields, but also intersects with business majors, supply chain, and social sciences in many ways.

With our relatively new effort studying EV usage patterns we have already had many chances to intersect with students and develop further understanding about EV usage. For example the author teaches a solar device technology class with thematic semester projects required of all students. Recently one of these project assignments was aimed at having the students design parking-lot solar-arrays with the added feature of stationary battery storage for storm resiliency. Also, one engineering capstone design team is underway examining electricity usage by EV fleet vehicles being operated by the university – with the aim of providing advice about recharging strategies and understanding total cost of ownership for these new vehicles.

EV data and energy strategies are also useful for outreach in a variety of ways. For example the author has given several presentations in the “Energy Café” series organized by the Rutgers Energy Institute. These are open to the public, though mostly attract interested students.

In the future we expect students to be engaged in research projects examining many facets of the electrification of transportation in the region. For example: Could EV’s be charged at the university’s solar array during storm/grid failures and then used for emergency delivery of power to critical facilities in the region? This would build on our recent probability model for guiding battery size for these resilient power islands (Birnie 2014).

Also, could electric buses be used within the sprawling university campus? What infrastructure, performance and environmental impacts would result (Rutgers maintains one of the largest bus systems in the state of New Jersey).

Further, could “vehicle-to-grid” (V2G) systems be fielded on or near campus? New variants of V2G

could be tested and evaluated within the context of a large commuter population, both of students and for faculty and staff. Again there are significant infrastructure, logistics, and social changes that will be required to allow for smooth operation of V2G and other complicated energy systems in the future.

Already we are increasing our data gathering capabilities and will be connecting these data with driving habits, seasonal temperature variations, and commuting routes. Our overall aim is to have students involved in the data gathering, analysis, and interpretation so that we can increase the impact for regional transportation modification in the future.

5 INSTALLATION ISSUES

The transformation that we envision is hampered significantly by the infrastructure needed to provide power to growing numbers of commuters. The EV charging hardware is only part of the story as electric conduit may have to be laid and new circuits added, depending on the location and anticipated number of vehicles to be serviced. Up to this point these infrastructure costs are quite a bit larger than the value of the electricity that the vehicles receive.

Also, the EV equipment that we have installed so far has been added with relatively little consideration of the population of likely users and their charging habits and how this impinges on the general limitation on availability of parking. And, the question of different usage patterns that will match with Level 1, Level 2 or higher power rates has not been clarified.

The best strategy will likely be to combine new EV charging locations with new construction projects and building renovations so that the rewiring and new hardware can be made as cost-effective as possible. And, there may be new ways of co-funding for charging units that will be used partly by the university fleet and partly by the student/faculty/staff private vehicles. This is a wide-open discussion that is evolving rapidly on campus as we move this initiative forward.

6 POLICY CONNECTIONS

Our studies of electric transportation integrate the technological (hardware and algorithms) with the social (attitudes and behaviour patterns). In many cases these combined socio-technological changes will be assisted by policy choices that we make

along the way (local to campus, but also state and federal policies, as well). For example, the IRS has issued a ruling that electricity provided without cost to employees in workplace charging is of “*de minimis*” value and thus not a taxable benefit. And, some regions have given EVs priority in the High Occupancy Vehicles (HOV) lane, providing encouragement for rush-hour commuters to change to electric-drive vehicles.

Another gradual policy push will come from the steadily increasing fuel efficiency standards imposed on car manufacturers, thus giving preference to electric vehicles that can take advantage of regenerative braking and generally have higher effective fuel efficiencies.

And, we have certainly seen that local policy choices have had an influence on EV usage patterns (for example the EV-only parking space interference by gasoline vehicles when no enforcement policy was in effect).

In the long run we hope to establish local policies that encourage our community to rely on EVs for commuting to campus and to appreciate the environmental advantage provided by moving from gasoline to electricity.

7 CONCLUSIONS

Large university campus locations are ideal for installing, studying, using, and developing technology needed for the coming transition to pervasive electric personal transportation. The involvement of students in these studies and in the classroom provides an excellent chance for the future leaders of our country (our students) to interact with the technology in the formative stages of their lives and then eventually participate in the continuation of this transition when they join the workforce.

ACKNOWLEDGEMENTS

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