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(Working Paper Jan, 29th 2013)

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ABSTRACT

Electric vehicle travel and charging was simulated using gasoline vehicle travel information from approximately 15,000 households in the CalTrans 2001 California Statewide Travel Survey. Ranges of 60, 80, and 100 miles were simulated to investigate the travel that could not be completed with home charging alone. Different types of chargers including workplace level 1 and level 2 chargers, level 2 public chargers, and DC quick chargers were then posited to determine the effect of each charging type on electric vehicle miles traveled (eVMT). If all statewide vehicle were 80 mile range battery electric vehicle (BEVs) and began the day with a full charge, 71% of miles (95% of home-based tours) are possible with home charging alone. Travel that requires some charging accounts for a corresponding 29% of miles (5% of tours). Workplace charging can enable about 7% more eVMT, public level 2 at stops greater than 1.5 hours could provide an additional 4% of eVMT, and quick charging could provide an additional 12% of eVMT. 6% of eVMT (0.6% of tours) would be difficult to complete in an 80 mile range BEV. 200 DC fast locations could provide an initial network to serve most Californians with the number of chargers growing past 200 to handle congestion at charging areas. Scenarios for plug-in hybrid electric vehicles (PHEVs) show that for a 30 mile range PHEV, 61% of miles could be completed with home charging alone.

INTRODUCTION

Plug-in electric vehicles (PEVs) including BEVs and PHEVs, are now available from major carmakers. As buyers move from early adopters to the mass market, the question of “what sort of charging infrastructure is needed to serve the market of the future?” becomes important. This question is a multi-faceted one, the answer to which depends on the make-up of the future market including whether vehicles are predominantly BEVs or PHEVs and of what size batteries. The question of what type of charging infrastructure is needed has been covered in many studies. This paper extends that work by using a geographic tour based framework to explore the benefit that level 1 (L1), level 2 (L2) and DC quick charging (QC) could provide using different charging and vehicle technology scenarios. The advantage of this method is that the whole tour can be modeled - from the time a vehicle leaves home to the time it returns home – enabling a full assessment of how much charging may be needed and at what type of location category. The location categories include home, work, and public.

The approach in this paper uses the home-based tours of gasoline vehicles taken from a California Statewide travel survey done by CalTrans in 2001[1]. The survey recorded actual trips by drivers where the driver noted the location name and type. By examining how current travel patterns in gasoline vehicles could be completed in various types of PEVs an assessment can be made as to what charging infrastructure might be needed in the future at home, work, and in public and at different charging speeds including level 1, level 2 and DC fast charging.

BACKGROUND

The demand for charging is derived from the demand for plug-in vehicles (PEVs) and from the travel patterns expected for these vehicles. Recent studies on the demand for charging are primarily focused on the aggregate demand for electricity and the energy and environmental impacts derived from PEVs [2,3,4,5,6,7]. Similar studies focus on the cost effectiveness of battery size and charging infrastructure based on infrastructure availability assumptions [8,9]. Other studies are trying to model the impact of charging infrastructure on PEV demand using agent based models[10,11]. These studies are based on simplified travel patterns using on aggregate data and are geared to highlight the impact of travel demand on vehicle type but are not suitable identify charging locations.

Some have estimated the frequency charging may be needed using vehicle travel patterns. To obtain exact travel patterns, GPS tracked vehicles were used in several studies estimating the demand for charging. Gonder [12], for example, used GPS traces of 227 vehicles for one day to simulate the energy consumption and the potential of PEVs. The Gonder study focuses on the impact of different vehicles and battery size but does not explore the need for charging or the demand for PEVs based on travel behavior. A longer time frame using GPS for a full year was used by Pearre et al. The study is based on a year of driving data from nearly 500 instrumented gasoline vehicles, and showed that 9 percent of the vehicles never exceeded 100 miles in a day. For those who are willing to make adaptations six times a year -- borrow a gasoline car, for example -- the 100-mile range would work for 32 percent of drivers” [13]. The study also explores the question of how much range is required for a daily driving. This paper reveals the impact of long range relatively low frequency trips on total vehicle miles traveled (VMT) but again does not explore how charging may address the need for and impact of charging infrastructure. Recent attempts to use GIS tools to model the spatial demand for charging infrastructure include a raster approach that takes into account location attraction [14,15] Others use network analysis that estimates the need for charging based on tours assigned to the network and modeling of the vehicle battery level [16,17,18].

Charging simulations in this study will follow the tour based method as in similar studies by the authors [17,18] to integrate home, work, public level 2 and DC quick charging in a comprehensive way. This method uses actual travel data from a statewide travel survey[1] differs from other charging estimations by allowing charger simulations both spatially and temporally from actual rather than simulated data.

METHODS

In order to study to what degree California statewide travel could be completed in an electric vehicle, the origins and destinations of gasoline vehicles from the 2001 CalTrans Survey[1] was used to represent typical travel destinations. From these origins and destinations, we construct travel paths using a shortest time algorithm assuming free-flow traffic and assuming travel at the speed limit. As such, this does not exactly mirror reality, but at the same time is a reasonable estimation of it. A more detailed representation of actual traffic flows is reserved for future analyses. BEVs and PHEVs of different battery sizes were assumed to follow these travel paths, and charging scenarios were posited to enable travel to be completed where home charging was insufficient to enable all-electric travel. The charging levels tested are shown in Table 1.

	Voltage	Amperage	Power	Scenario Tested	Miles per 15 minutes
Level 1	120V	<20A	<2.4kW	1.2kW	1mi
Level 2	240V	<80A	<19.2kW	3.3kW,6.6kW	2.75mi, 5.5mi
DC Fast (QC)	200 - 450V	<200A	<90kW	50kW	41.7mi

Table 1 Charging level overview.

The miles per 15 minutes column represents the number of miles a vehicle could gain in the scenarios by plugging in assuming the vehicle has an efficiency of 3.3 miles per kWh.

While assigning all statewide travel to a particular vehicle type is unrealistic, the scenarios can be scaled to the market so that if a BEV or PHEVof a particular type is expected to sell at certain level, the results from this analysis for that BEV or PHEV type can be similarly scaled.

Survey Data

The 2001 CalTrans survey[1] was a one-day (in some cases 2 day) travel diary which focused on weekday travel. As such, there are some limitations as to what can be done with the data. While a snapshot of travel for a day can be reasonably estimated, travel on a household level cannot be estimated. For example, if a driver happened to take a long trip on the survey day, this long travel cannot simply be extrapolated to represent travel for the year for this particular driver or household. Conversely, we can reasonably postulate that the sample, in this case about 26,500 drivers, taken as a whole could represent statewide travel for a random sample of 26,500 drivers on any given day. We further postulate that with the proper scaling, the sample of drivers can, at some aggregated scale, represent all travel in the state. One drawback of the survey was that destinations for out of state travel were not available, leaving popular destinations such as Reno and Las Vegas unrepresented in the data.

Tour Creation and Data Preparation

The basis for analysis was home-based tours. A home-based tour in this case represents the travel done in a vehicle from the time it leaves home to the time it arrives home. This distinction is convenient in that we assume that a charger available at home is a given for analysis. There are of course other charging regimes such as purely workplace charging for those with no home charger, but this possibility is not explored. A typical tour would be: Home to work, work to store, store to home. As a matter of convenience, all tours that involved an alternative mode such as biking and public transit, were excluded from analysis. This resulted in 26,561 individuals of driving age (of 31,898 total) from 15,591 households taking 100,519 trips and 36,006 tours. 7,770 individuals of driving age (9,230 total) did not travel on the survey day. There were 31,074 household vehicles available. An overview of survey travel is shown in Figure 1.

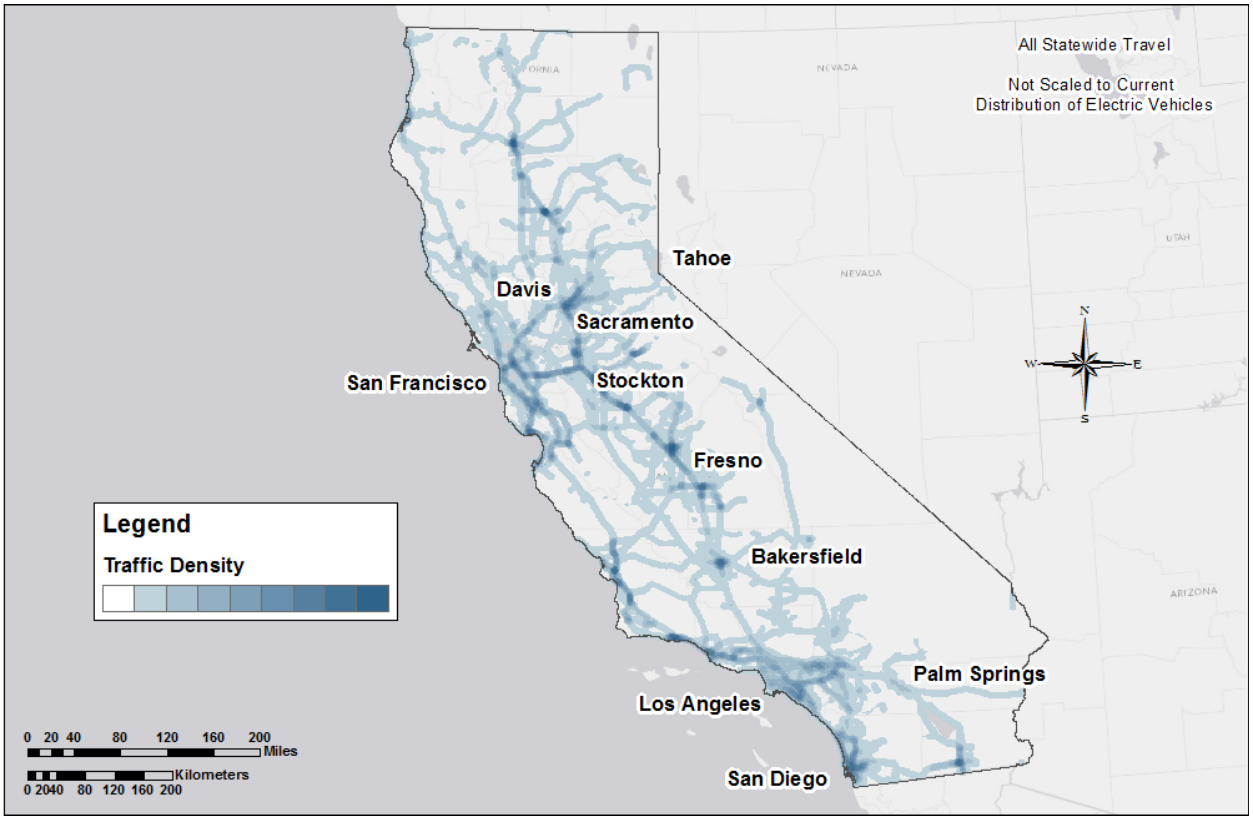

Figure 1 Density of statewide travel from the CalTrans 2001 survey.

As stated earlier tour routes were determined based on a shortest time basis between origins and destinations using speed limits to estimate speed. The calculations were performed with ArcGIS software.

Charging Model

The BEV charging model had a few basic rules: No vehicle was allowed to go below 20% SOC unless it was returning home in which case it was not allowed to go below 5 miles range left regardless of SOC. Drivers had perfect knowledge of the charging network and knew if the next charger could be reached within the appropriate SOC or mileage limits. Depending on the scenario, different charging infrastructure was available. The scenarios included a mix of home, work, public level 2 and public DC quick charging. An example tour is shown in Figure 2 and the corresponding operation of the model is shown in Figure 3.

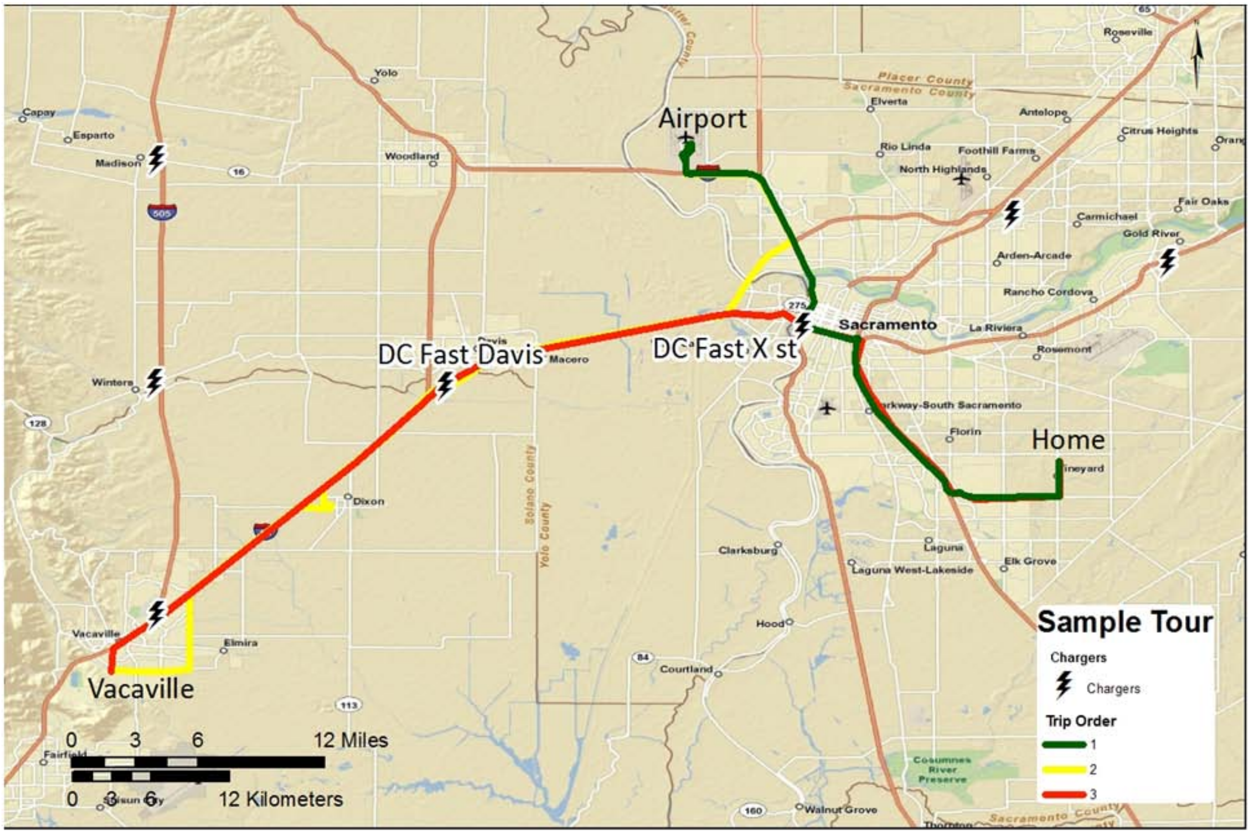

Figure 2 Example of a tour composed of 3 trips. Three quick chargers are available on this tour.

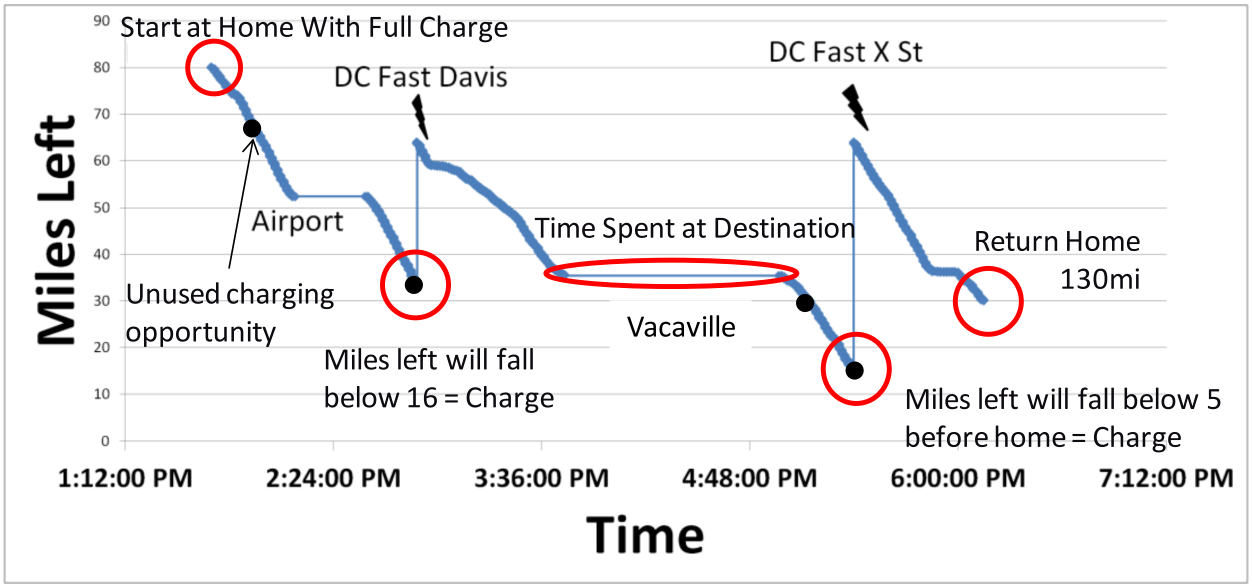

Figure 3 Model of a tour completed with a combination of home charging and quick charging. In alternate scenarios, the time spent at a destination could be used to charge, obviating the need for the second charge.

The model was run within ArcGIS by first constructing a series of points along the tour paths at ¼ mile separation between the points. Each point was identified by its position along the path on which it was located. For example, a point would have the value of 60 miles from home. This point also had a corresponding distance to empty (DTE) value. Using the previous example, in an 80 mile range vehicle, the DTE would be 20 at 60 miles from home. Additional information about the point was also known such as the distance to the next charger, and the distance to return home. Based on these values, when a charger was reached, the set of rules could be applied to determine if a vehicle should charge or could delay till the next charger. For the quick charging, a buffer of one mile was created around each potential site so that any path that intersected that buffer would be considered to be a quick charging opportunity. This implies that a diver might divert up to two miles to access a quick charger. The survey was scaled according to the total households per county as reported by the survey documentation divided by the household sample size per county. For example if 500 households from Los Angeles County were surveyed, and there were 3,178,460 households in Los Angeles, each respondent's travel would be multiplied by 6357 to represent the share of statewide travel.

The PHEV charging model was slightly different in that there was no fast charging option and that there was no 5 mile home safety buffer. Only a work scenario was completed and charging was only prompted when a vehicle could not return home on electricity alone.

Quick Charger Location Selection

While level 1 and level 2 chargers were assumed to be at the parking places of those in the survey, DC fast chargers (DC quick chargers) were placed differently. They were placed based on a route based flow capture model through a multi-step process. The first step in the process was to locate in a very rough way the locations where battery electric vehicles would run out of charge using tours in the survey. In this process, simulated vehicles of 60, 80, and 100 miles were set out on the network to complete their travel. When a vehicle reached 20% state of charge (SOC) assuming 100% SOC from home, a point was dropped on the network. The vehicle was allowed to continue, after a charge to 80% SOC, and drop further points at 20% SOC until the tours were complete. This resulted in 16668 initial points being dropped on the network. As the second step, these points were aggregated to 914 points using a k-means clustering algorithm. 914 points was an arbitrary number that was close to 1000, but limitations of the clustering program resulted in only 914 unique points. The clusters could represent one point or many points. Points that were far from other points represented one cluster while many points close to each other were aggregated to one cluster. These points were snapped to the road network to ensure flow capture of travel. The 914 initial quick charge points are shown in Figure 4.

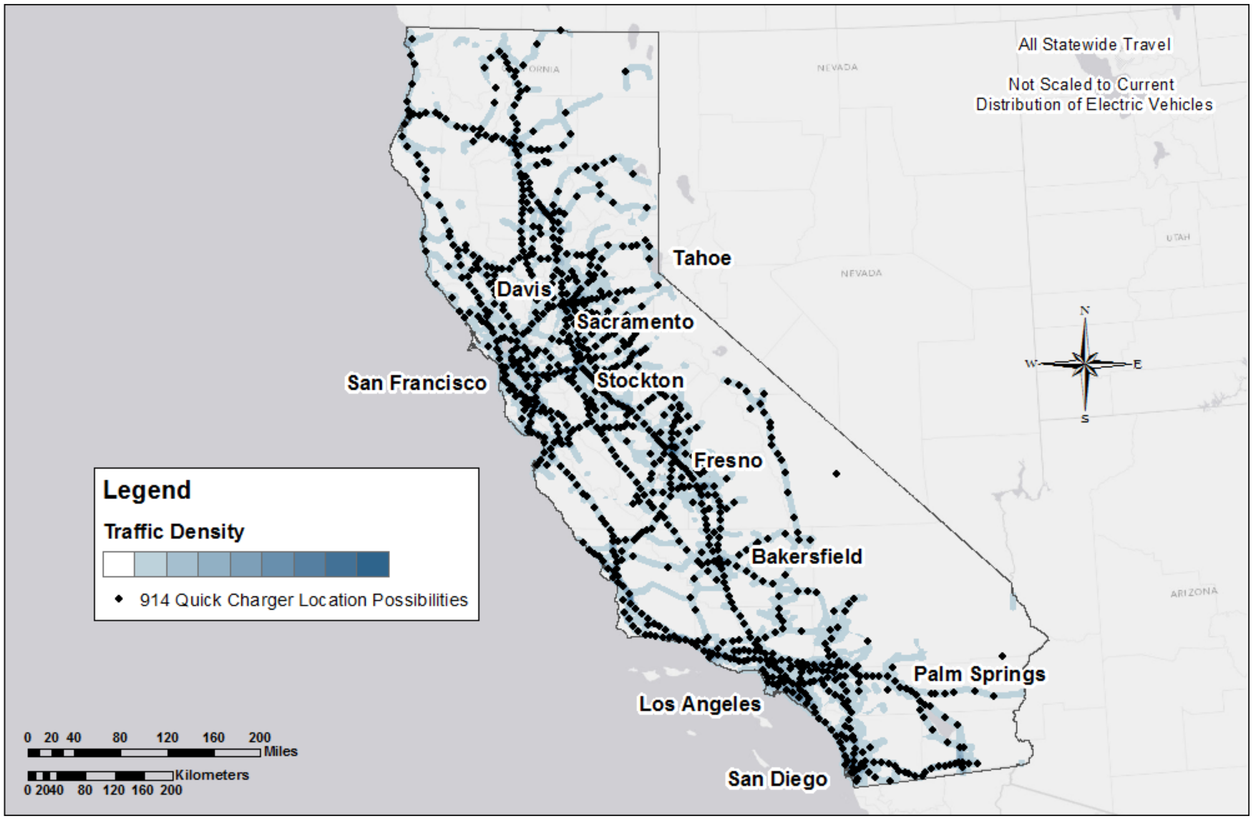

Figure 4 Initial quick charger location possibilities as the second step into determining the most useful charger locations.

Many of the 914 initial points were very close to each other meaning that one location could possibly serve the potential demand of neighboring sites. The third step therefore was to determine which of the 914 initial possibilities were redundant. The model described above was used in an iterative process to choose the best locations among the initial sites. The sites were evaluated by their ability to increase in the number of miles possible in an EV on tours that required 2 fast charges or fewer. Stopping every hour for one half hour on tours requiring 3 or more fast charges was deemed less likely to occur and those chargers that served mainly long tours were as a result de-emphasized. The process of down-selection is shown in Figure 5.

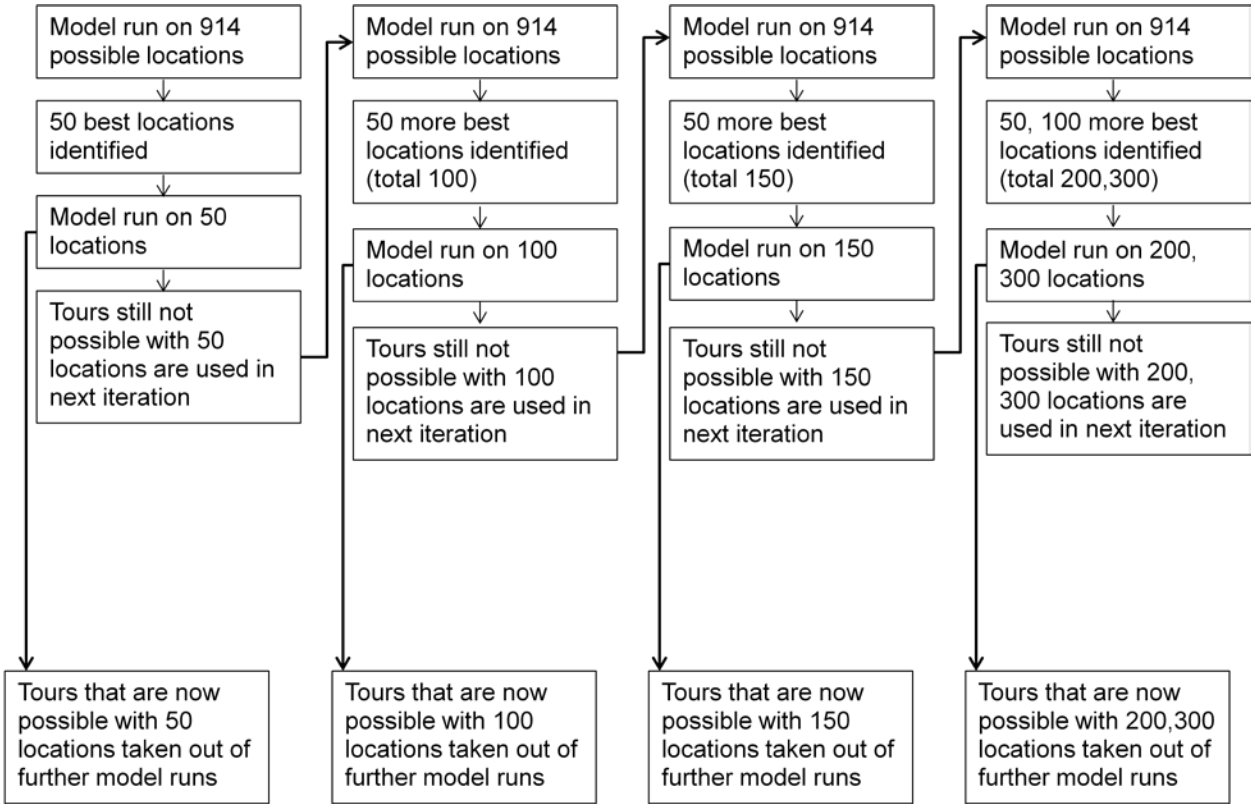

Figure 5 Process of choosing the best 300 quick charge locations from a possible 914.

After 200 locations were determined, there was very little marginal benefit to adding more locations. After 300 locations, there was even less marginal benefit to adding locations so the iterations were halted. After 200 locations the only tours that remained in the model were tours not taken by many vehicles or that the tours were long requiring 3 or more charges per tour.

The process of incrementally increasing the number of sites with each iteration was preferred to simply running the model and choosing the top 300 sites. When simply choosing the top 300 locations was done, it resulted in many redundant stations in urban areas and little accessibility elsewhere. When the iterative process was used, more total miles were possible with the same number of locations.

RESULTS

The results can be divided into three categories:

- Potential DC quick charging needs statewide
- Relative benefit for BEVs of home, work L1, work L2, public, and DC quick charging
- Benefit of home and workplace charging for PHEVs.

Potential DC Quick Charging Needs Statewide

The results of the quick charging scenarios show the potential usage of quick chargers by vehicles with 60, 80, and 100 miles range. Since the usage is estimated by positing that a BEV of a certain range must be used to make a journey, the results should be interpreted in terms of access to travel options rather than an estimate of usage. Since many BEV owners also have a gasoline vehicle, if the price is too high to quick charge or the duration to charge is too inconvenient, a gasoline vehicle may be chosen for travel rather than a BEV. Nevertheless, the concept of "accessible miles" can be used to evaluate the benefit of quick charging. Even though another car may ultimately be chosen for long trips, the results below detail the increase in access that a BEV has. Through the simulations, some salient points emerge.

Number of Locations vs Number of Chargers

The first point to emerge is that certain locations show higher potential usage than could be served by one charger. This is the case shown in Figure 6.

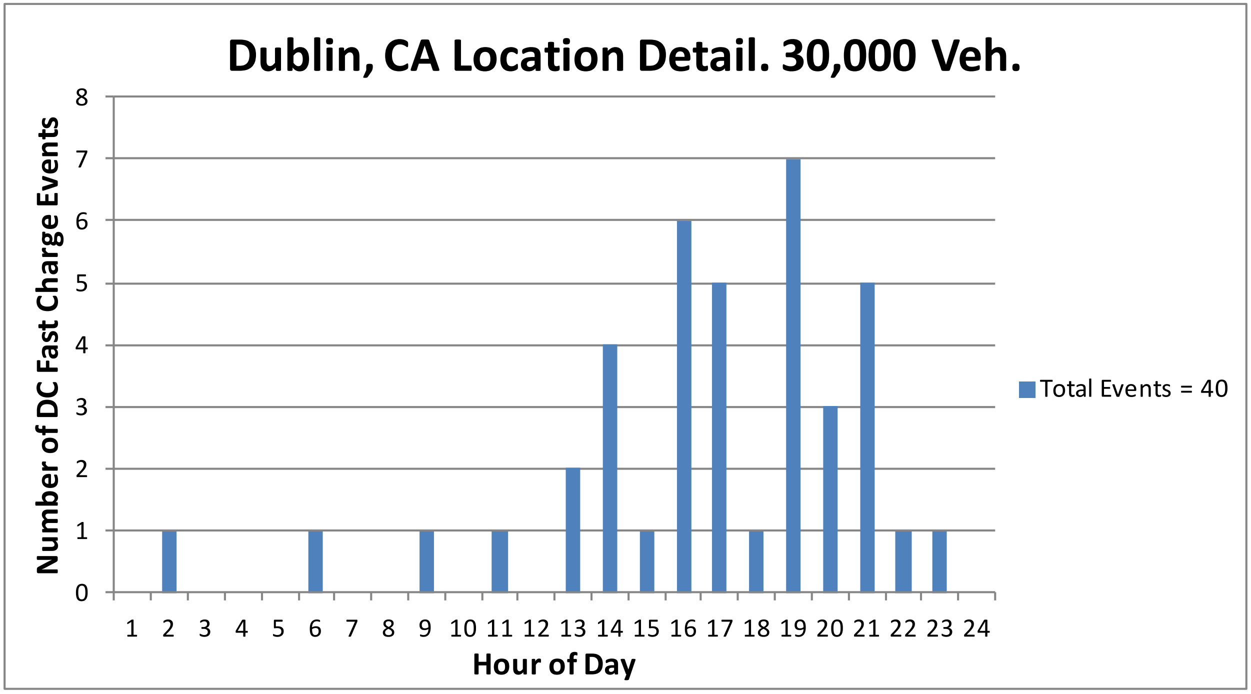

Figure 6 Detail of one fast charging location scaled to 30,000 vehicles.

During the 7 PM hour 7 events are simulated to occur. Assuming a quick charger can serve a maximum of three charges per hour, at least 3 charging stations would be needed near this location. Because of this, the number of *locations* is independent of the number of *chargers*. Locations can be very loosely interpreted as a city scale location and could move several miles in any direction without affecting the model results greatly. The three chargers mentioned in the example, may be all at the same location or several miles apart.

Number of Quick Charging Locations Statewide

The second point to emerge is that that to enable most travel around the state little benefit was gained in terms of miles traveled after 200 locations (Figure 7).

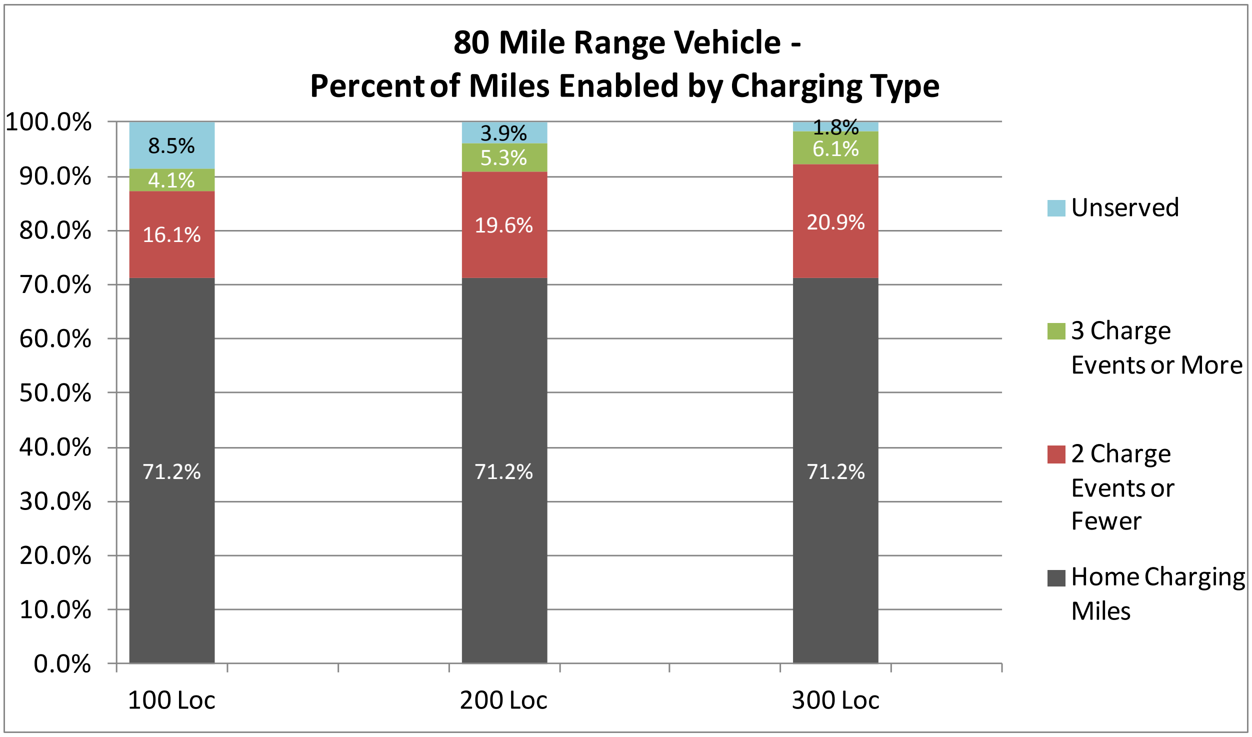

Figure 7 Miles enabled statewide by either home or quick charging for an 80 mile BEV

The results are displayed in terms of miles possible if everyone in California switched to an 80 mile BEV for one day. This does not represent miles on a household level as some households have destinations that are closer to home such that 100% of miles would be possible. The bottom 71% represents miles statewide on relatively short trips that could be completed with only home charging in an 80 mile range vehicle. This 71% corresponds to 95% of tours meaning the top 5% of tours represent 29% of the miles that are "unserved" with only home charging. Representing the unserved tours in terms of mileage instead of number of tours highlights the energy and greenhouse gas implications more precisely.

Looking at Figure 7, if only home charging and 100 locations were available statewide, 16.1% more miles would be possible if quick charging were available. With 200 locations, the number of miles increases to 19.6% and with 300 locations, 20.9% more miles are possible on tours of 2 quick charges or fewer. With 200 locations available statewide, only 3.9% of miles are not possible showing that 200 locations (independent of the number of chargers) should be sufficient for an initial network of quick charging stations. Scenarios for 60 mile and 100 mile BEVs were run as well (Figure 8 and Figure 9).

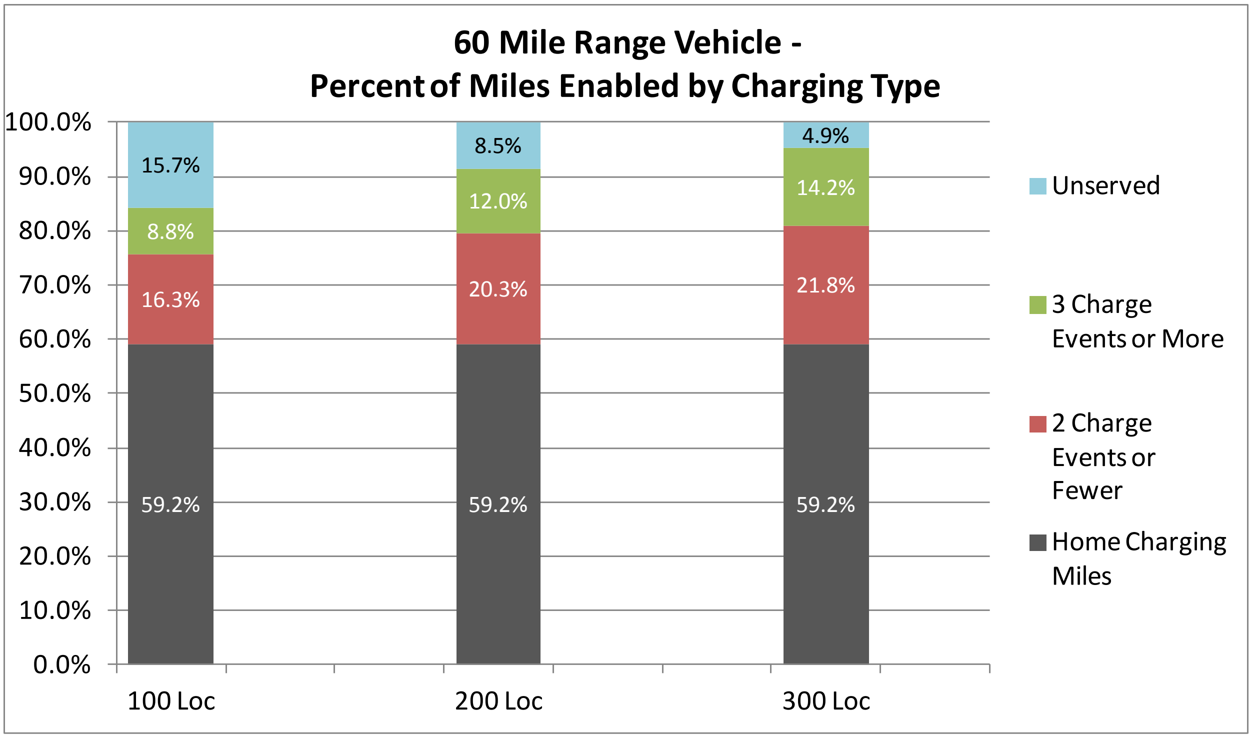

Figure 8 Fast charging potential in terms of accessible miles for a 60 mile range vehicle.

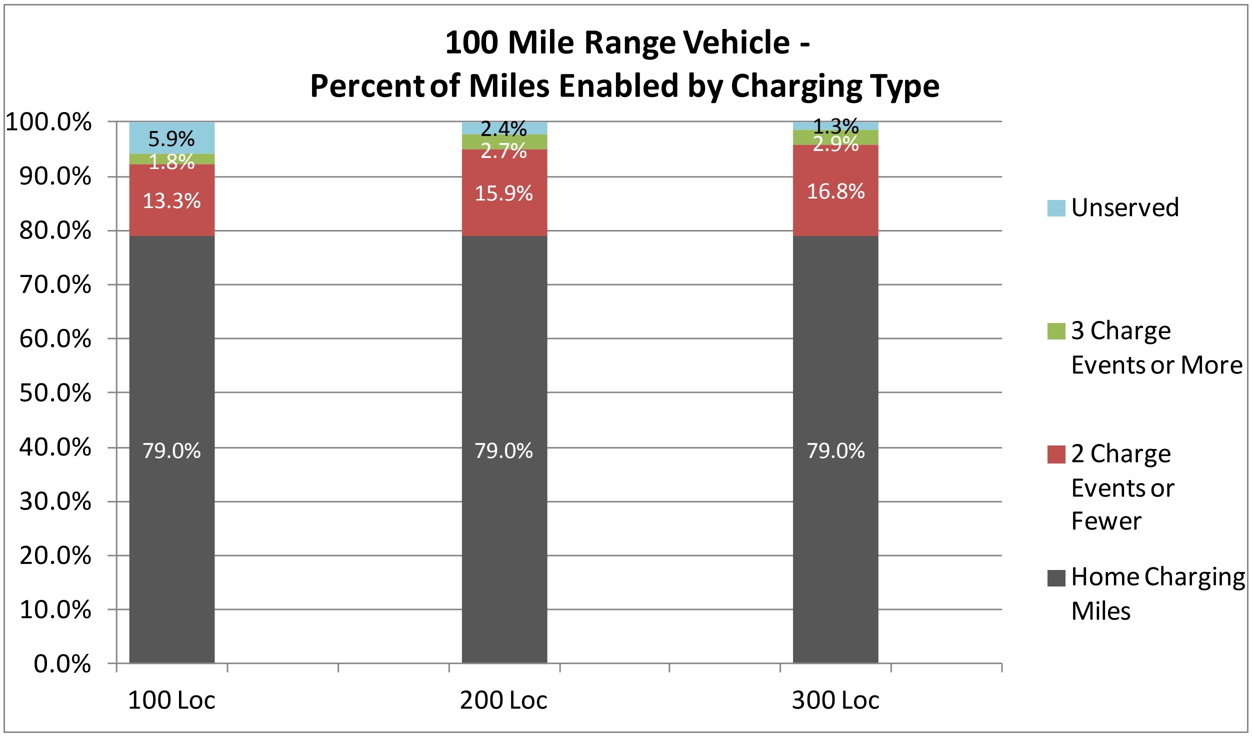

Figure 9 Fast charging potential in terms of accessible miles for a 100 mile range vehicle.

From Figures 7-9, we see that with simply home charging and 200 fast charge locations, only 2.4% - 8.5% of travel statewide, depending on battery size, is not possible suggesting that DC quick charging could serve as a bridge to ubiquitous L2 charging.

Number of Quick Charging Stations Statewide

The number of quick chargers necessary depends on the number of vehicles in the state. Looking at Figure 6 we see that three chargers are needed to deal with peak demand at one location. There are a total of 40 charges per day at that locaion. Using a simple calculation of charges per charger, a total of 15 charges per charging unit per day would give the correct number of chargers - three. 40 chargers divided by 15 equals 2.6 chargers needed at that site or roughly 3 chargers. Applying this logic for 1,000,000 vehicles we see a possible total number of chargers needed statewide in Figure 10.

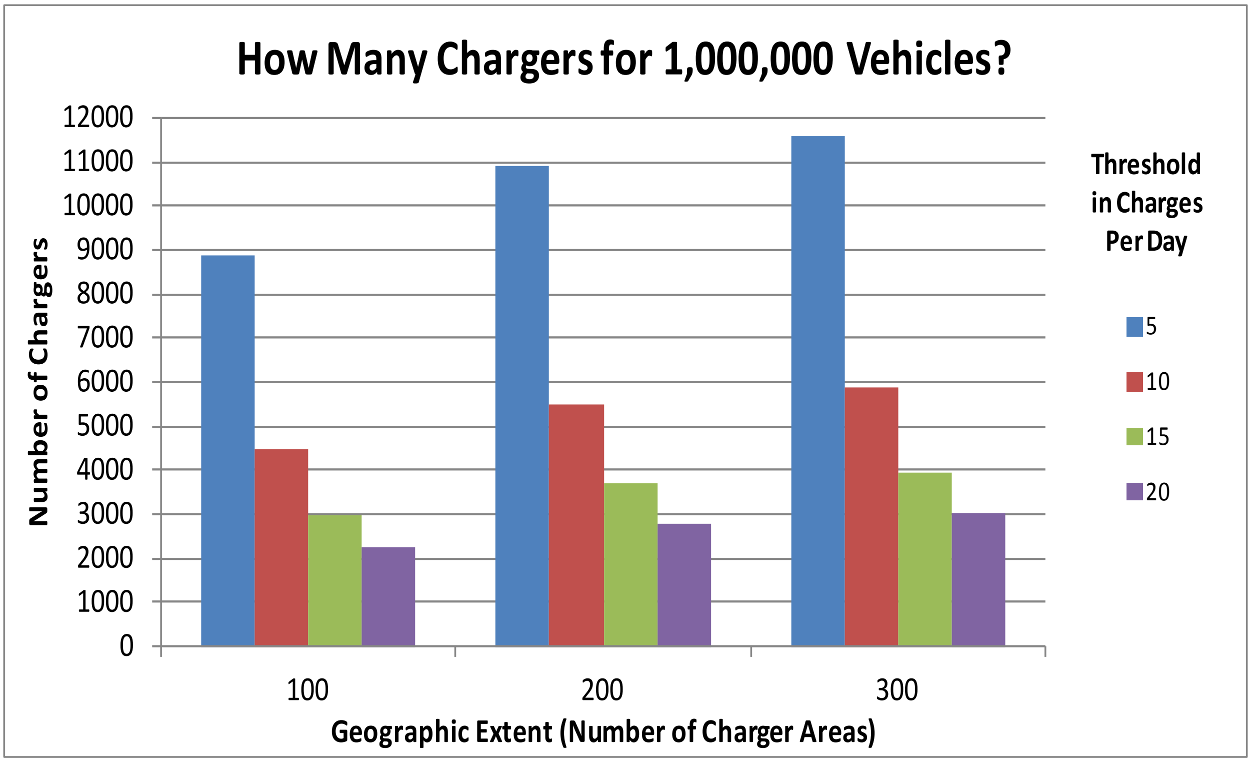

Figure 10 Scaling of the number of locations to the number of chargers for 1,000,000 vehicles.

The number of chargers here are to suggest an order of magnitude and not an exact number. Also, the locations at this scale do not suggest that all chargers be co-located at the same site. For example, there would not be 10 chargers per site assuming 2000 chargers in the 200 location case. The locations are meant to be suggestive of geographic extent. This scenario also assumes 80 mile BEVs. Other battery sizes, pricing and value of time may increase or decrease the number of necessary chargers. However, these results suggest that one charger for every 300-500 vehicles could be needed in a mature market. For 30,000 BEVs 200 locations results in 246 chargers needed at a 15 charges per day per charger threshold.

Quick Charger Geographic Distribution

The best locations for chargers can also be viewed in a geographic context. Using the projections of model, the relative usage of the chargers statewide can be seen in Figure 11 for 200 locations.

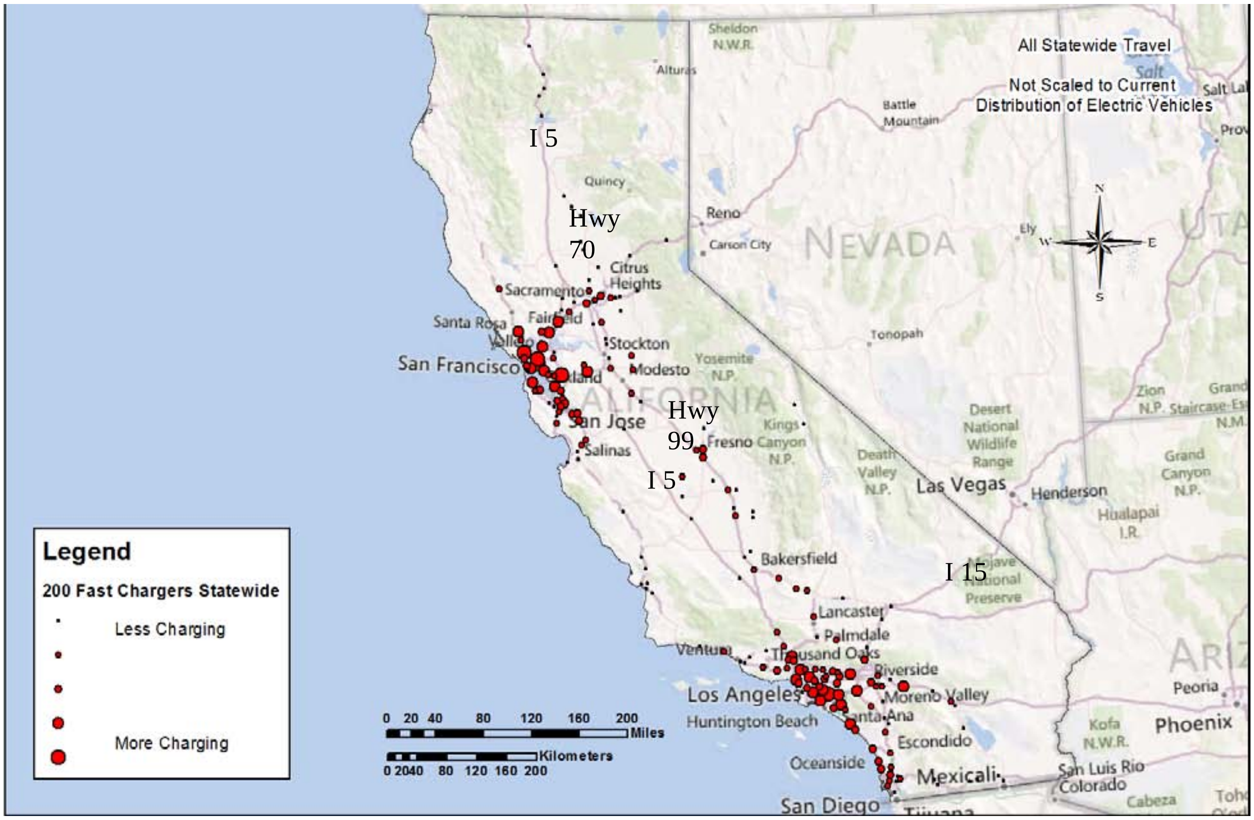

Figure 11 Model results from the 200 location scenario

Examining the charger placements the model made, we see a few themes. First, corridors connecting adjacent metropolitan regions together through adjacent-region corridors (ARCs) show high potential usage. The main corridors connect Sacramento to San Francisco and Los Angeles to San Diego. Secondly, significant usage appears within metropolitan areas where many medium distance trips are made.

As stated in the model setup, only charging on tours requiring 2 charges or fewer were used to evaluate charger placement. Consequently those chargers used primarily for long journeys were de-emphasized. This produces some noticeable absences in the network, namely the trans-regional corridors (TReCs) of Interstate 5 connecting Los Angeles to San Francisco, Interstate 5 connecting Sacramento to Oregon and Interstate 15 connecting Los Angeles to Las Vegas. However, in the case of Interstate 5, alternate routes appear that connect northern and southern California along Highway 99 and Highway 70. These routes follow population centers more closely and suggest a dual use of both local and occasional long journey travel. As battery sizes grow larger, travel on Interstate 5 will prompt the installation of chargers on these long distance routes. Travel to Las Vegas was not used in the model selection as travel was out of state. Not taken into account were the desires of EV owners to have access to these main travel corridors whether they would use them or not. Having chargers along these long distance routes may increase sales of BEVs and so some utility can be gained from them in the absence of usage.

Relative Benefit for BEVs of Home, Work L1, Work L2, Public, and DC Quick Charging
Quick charging may be expensive and may require a driver to interrupt a journey to utilize it. If available, drivers are expected to prefer level 1 or level 2 charging while parked especially on habitual trips. In order to test the sensitivities of this, charging was available at every workplace in the model at 1.2 kW L1, 3.3kW L2 and, 6.6kW L2 for different battery sizes for 100 QC locations and 200 QC locations (Figures 12-14). To highlight just the charging, no home charging is shown.

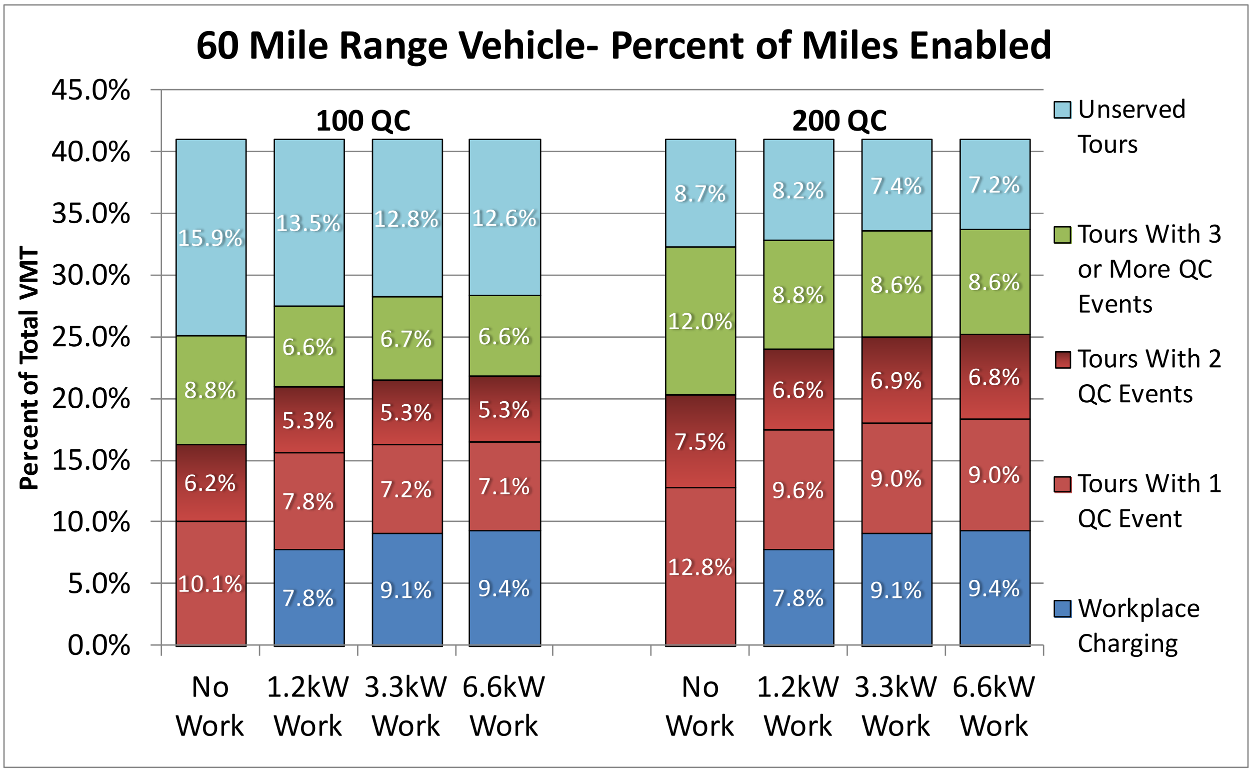

Figure 12 Effect of workplace charging on quick charger usage on BEVs with a 60 mile range. 59% of miles (not shown) is possible with home charging.

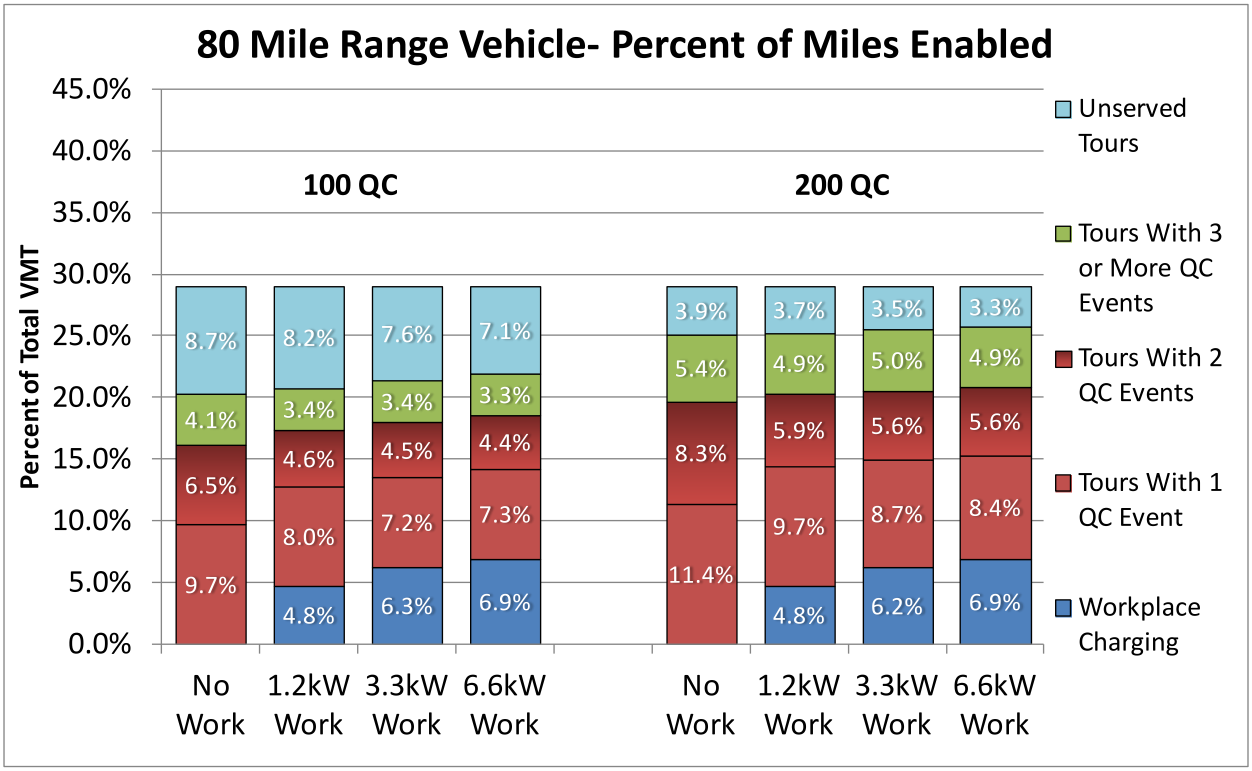

Figure 13 Effect of workplace charging on quick charger usage on BEVs with an 80 mile range. 71% of miles (not shown) is possible with home charging.

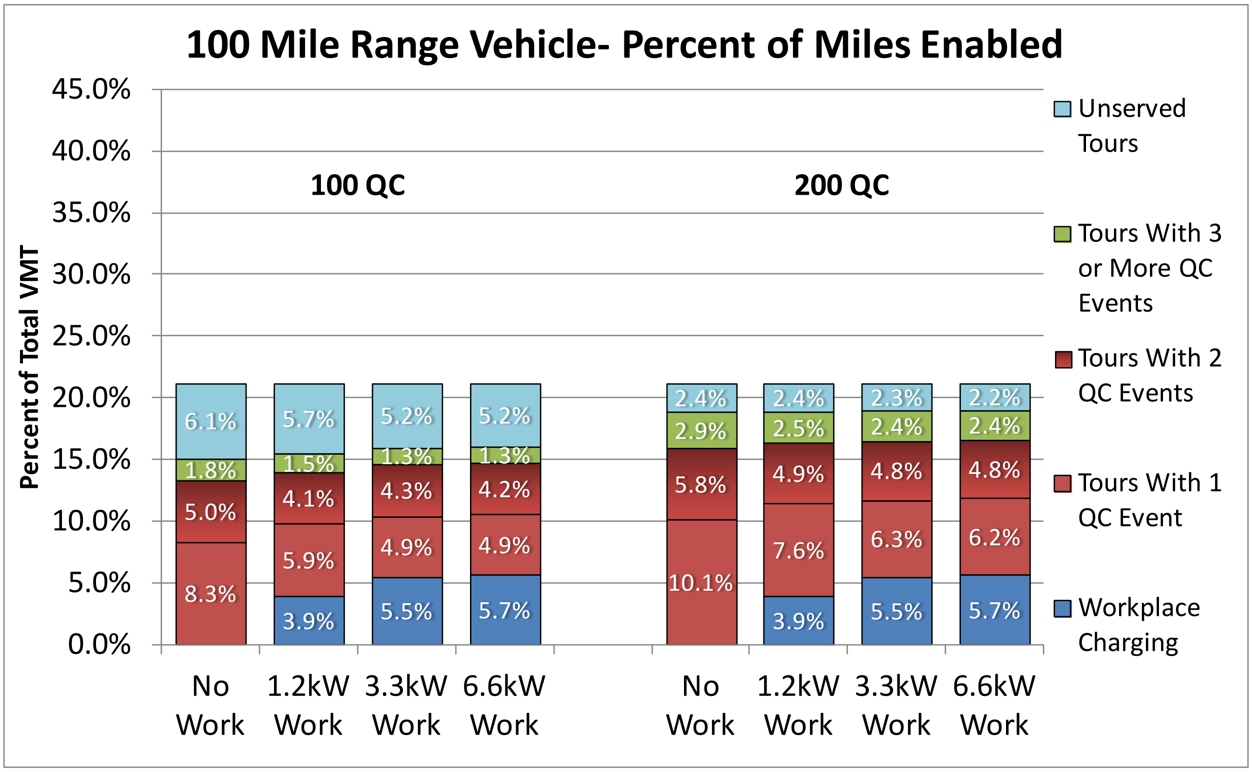

Figure 14 Effect of workplace charging on quick charger usage on BEVs with a 100 mile range. 79% of miles (not shown) is possible with home charging.

First, with all the scenarios, the workplace charging replaces much of the apparent demand for quick charging. As quick charging is unlikely to be done on a habitual trip such as a commute, the estimates of QC potential that include workplace charging are likely to be more realistic. However, in the case of the 60 mile range vehicle, the large increase in miles accessible between the pure QC scenario and the workplace + QC scenario shows that workplace charging is used in conjunction with QC. This too may be unlikely on a habitual trip.

The second salient point is that level 1 is sufficient for much of the workplace charging. In the case of the 80 mile range vehicle, workplace level 1 is sufficient for 4.8 percentage points out of a possible 6.9 percentage points meaning that level 1 can account for 70% of electricity at the workplace. As the 30% of energy supplied by L2 would be dispensed at a faster rate, more than 70% of chargers for BEVs at the workplace could be level 1. A 60 mile BEV translates to 83% of electricity possible on level 1, and for a 100 mile BEV, level 1 can account for 68% of the electricity dispensed at the workplace.

Adding public level 2 at 1.5 hour stops into the model results in an increase of miles possible. Collapsing the bars in Figure 13 and adding public level 2 results in the charging potential shown in Figure 15.

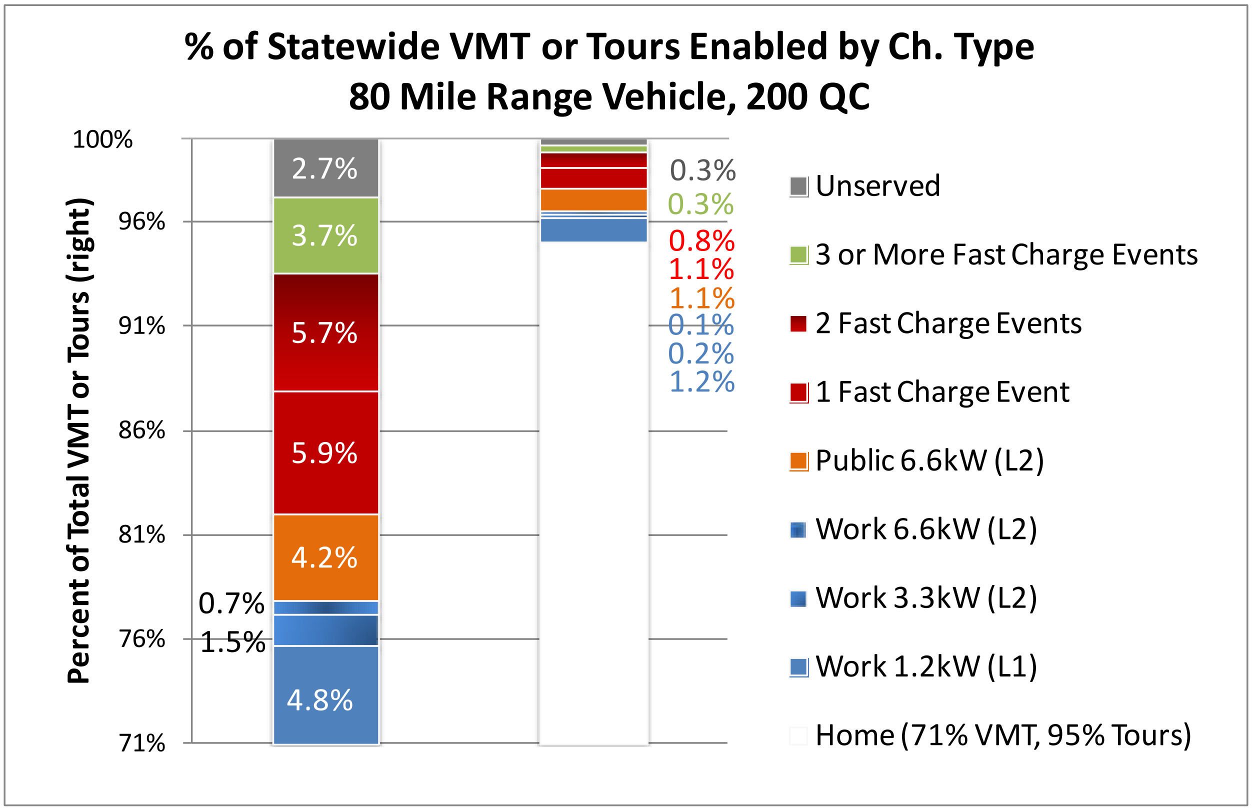

Figure 15 Complete charging potential picture by type of charger for an 80 mile range vehicle shown both in terms of percent of statewide vehicle miles traveled (VMT) gained and percentage of statewide tours covered

Figure 15 is a summary of many findings for BEVs already outlined

- Much of statewide travel is possible with only home charging
- Longer tours that require charging are only a small percentage of total statewide tours
- Level 1 is sufficient for over 70% of BEV chargers at the workplace
- Some level 2 is needed at the workplace for longer commutes or shorter parking duration
- Level 2 at stops greater than 1.5 hours can provide 4.2% of VMT statewide
- Even with the maximum workplace and generous public L2, some tours cannot be completed without quick charging
- DC quick charging can expand the travel possible accounting for an extra 10% of statewide VMT in many cases assuming charging is available at work and in public

PHEV Workplace Charging Model Results

Analysis of PHEV travel and charging is also possible using the survey data. Scenarios were run with PHEVs having battery sizes ranging from 10 miles all electric range to 100 miles all electric range. Assuming home charging to 100% and charging whenever a vehicle returns home, a picture of eVMT emerges shown in Figure 16.

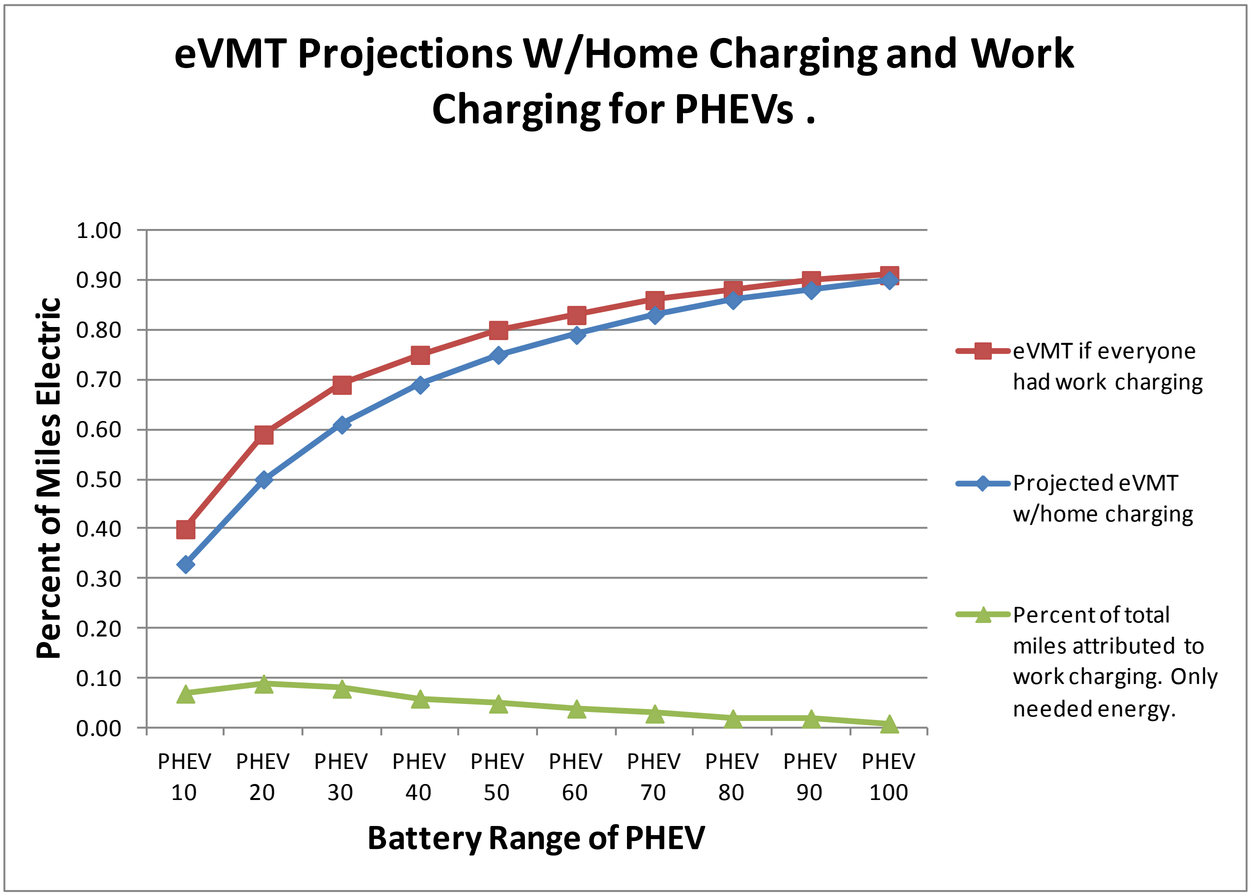

Figure 16 Proportion of total electric miles traveled possible using home and workplace charging with PHEVs of various battery sizes.

Figure 16 shows that PHEV 20s receive the greatest benefit from workplace charging over only home charging. This is the result of both battery capacity and distance to work. The battery size matches most closely with commute distance so the vehicle is likely to arrive at work empty. Although the PHEV 10 is more likely to show up at work empty, it does not have the capacity to store enough energy to return home as much electrically powered as the PHEV 20. The PHEV 30 can store more energy, but is more likely to be able to return on electricity mostly from home.

The effect of level 1 (1.2 kW) versus level 2 (5.9 kW) charging at work for PHEVs was also tested. In all cases, the percentage of eVMT statewide for level 1 at work was within one percentage point of level 2 indicating that for PHEVs, level 1 is sufficient at work in almost all cases regardless of battery size. For the effect on the grid of level 1 vs. level 2, Figures 17-19 detail a scenario of 30,000 PHEVs of various sizes.

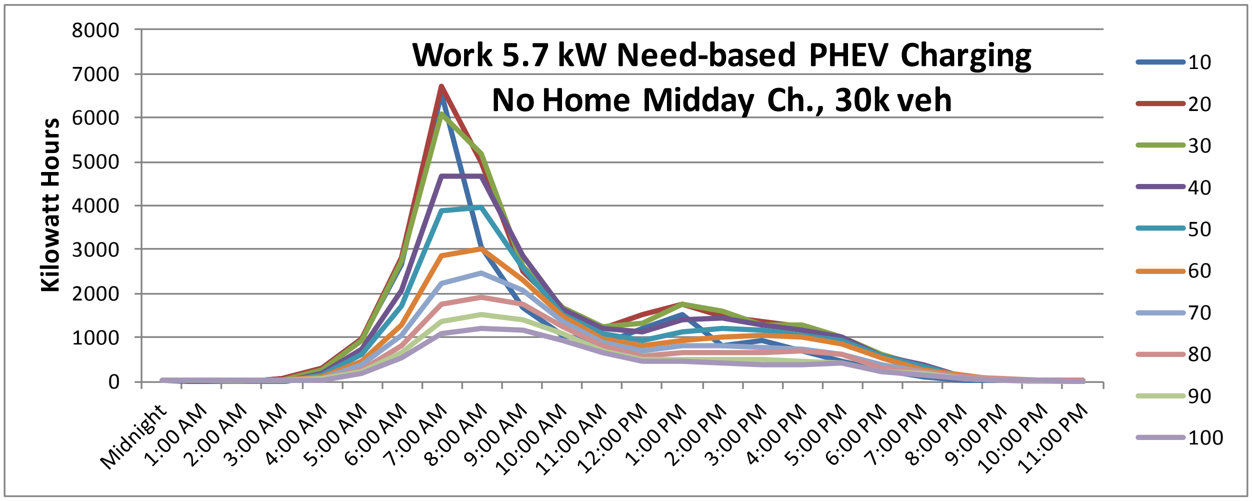

Figure 17 Scenario of grid effect of workplace charging at 5.7 kW for 30,000 PHEVs. This scenario assumes that vehicles only plug in if they are not able to return home on electricity alone.

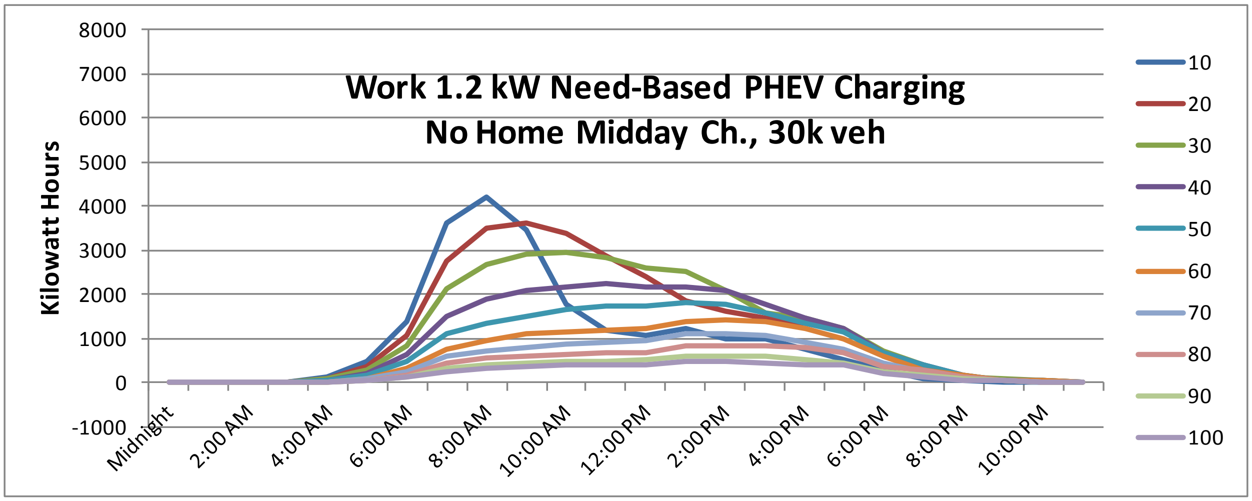

Figure 18 Scenario of the grid effect of workplace charging at1.2 kW for 30,000 PHEVs. This scenario assumes that vehicles only plug in if they are not able to return home on electricity alone.

When comparing the number of electric miles possible between the two scenarios in Figure 17 and Figure 18, there is virtually no difference in the number of electric miles possible with level 1 vs. level 2 but there is a possible negative grid effect as charging is completed later in the day.

Looking at the effect of midday charging at home, a scenario was run to see the charging in addition to workplace that would be needed to maximize eVMT (Figure 19).

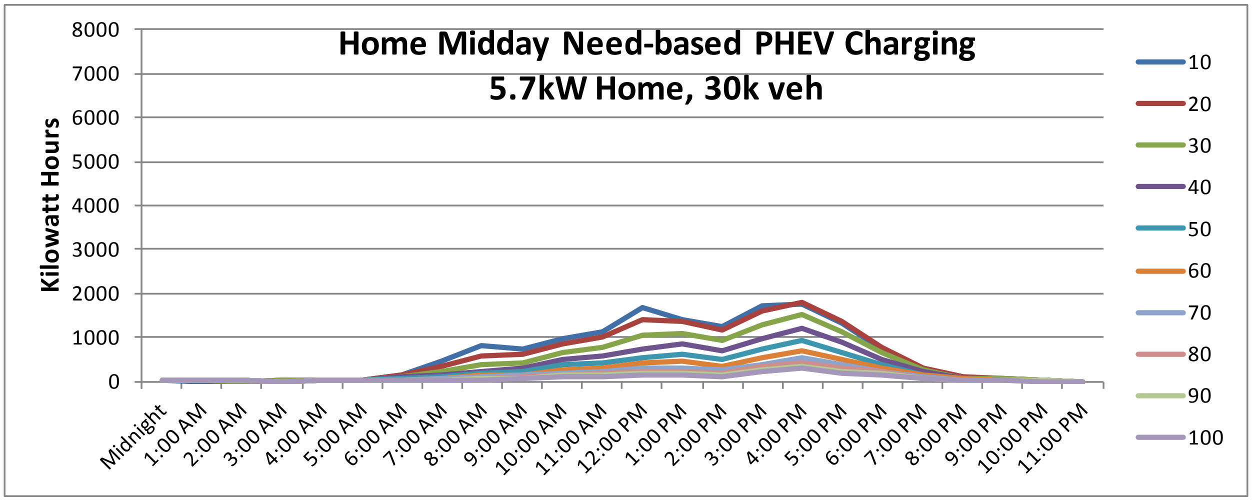

Figure 19 Scenario of grid effect of midday home charging at5.7 kW for 30,000 PHEVs. This scenario assumes that vehicles only plug in if they are making a home based tour and are not able to complete the tour on electricity alone with the remaining battery SOC.

Figure 19 details the home-based charging needs for those whose battery state of charge is insufficient to make a home-based tour on electricity alone and have space in their battery to put in energy. Since everyone in the scenario is assumed to have 100% SOC at 3AM, the charging in Figure 19 reflects charging only after a vehicle has already made one home-based tour and empties their battery to some degree. Figure 18 does not reflect the overnight charging that must be done to return the battery to 100% SOC.

To explain more thoroughly the assumptions in the PHEV charging model and the influence price might play, three scenarios are shown for a PEHV 40 with different assumptions in Figure 20.

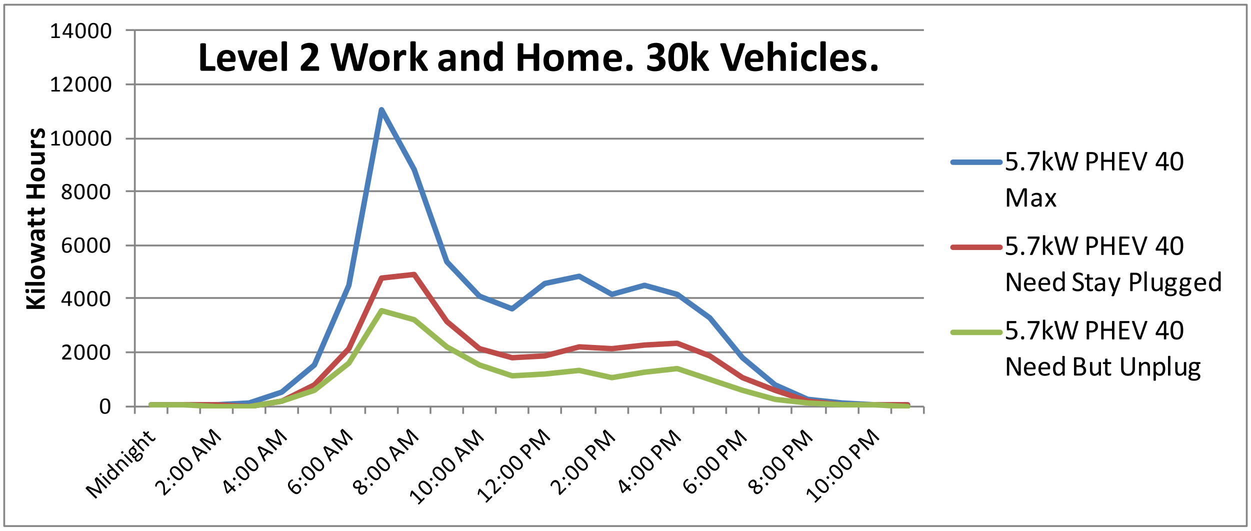

Figure 20 Scenario of grid effect of different charging behaviors. The top line assumes everyone plugs in at work regardless of need and could correlate to free workplace charging.

The top line in Figure 20 shows the effect if everyone who had a PHEV 40 plugged in at work regardless of whether they would need that electricity to return home. This is a likely scenario if work charging is free. The middle line, which follows the scenarios in Figures 17-19 assumes that a driver plugs in if he/she is not able to return home on electricity alone, but does not unplug when enough energy is transferred to return home. The bottom line assumes need-based charging, but the moment when enough energy is gained, the driver unplugs. All scenarios result in the same eVMT, but the costs and grid effects are shifted from home to work in the "max" scenario. Depending on battery size, customers could get an average of 1kWh-8kWh of power they don't need from work. If midday electricity generation is more GHG intensive than nighttime electricity or the grid must be strengthened to deal with additional load, there may be consequences to free charging at the workplace. Additionally, more chargers will be needed at work if charging is free because even cars that don't need electricity to return home will be plugged in at work.

DISCUSSION AND CONLCUSIONS

The model and underlying data allow for testing of many different scenarios. However, it is limited in the sense that it does not deal with travel from actual PEV households and cannot reflect "right-sizing" of vehicles such that a customer would match a vehicle to his or her particular driving patterns. Further, while it is possible to estimate potential in different charging scenarios, it is difficult to estimate the actual usage of charging. The actual usage of a charger depends on the price of charging and the time to charge among other factors. This sort of analysis will need more and better data to complete. Lastly, consumer preferences do not always match the model. For example, consumers may find value in DC quick chargers that they may never use but they would like to be able to. Determining this is difficult with a model and the model results will have to be supplemented with surveys

Keeping the above limitations in mind, we can quantitatively address many policy questions surrounding charging including charging location, number of chargers, charging speed, and charging price across a wide range of vehicle types.

Regarding charging location, there a two types: spatially explicit location and location category. The spatially explicit location is relevant to the location of DC quick charging. The location category includes home, work, public level 2 and DC quick charging. The simulations with quick charging showed that the most relevant locations for DC quick charging would be within metropolitan regions, connecting suburbs with regional centers, and along adjacent-region corridors. As the simulations limited demand to 2 or fewer quick charges per tour, long distance corridors did not appear prominent in the analysis unless they were surrounded by population centers. As battery sizes grow, or consumers prove to be tolerant of stopping more than 2 times on a journey, charging along these corridors may be important.

The location category simulations revealed what additional benefit could be gained from home, work, public level 2 and DC quick charging. Assuming only home charging BEVs achieve 59%-79% of driving miles statewide. PHEVs could be able to get 32%-90% of miles from only home charging for sizes ranging from 10 mile all-electric range to 100 mile all electric range. Work charging could add another 6% - 9% of miles for BEVs and from 2%-10% more electric miles for PHEVs. Public level 2 at non-work stops greater than 1.5 hours could add 4% more miles for an 80 mile BEV assuming workplace and home charging had been already been fully used. Quick charging could add another 16% more miles assuming, home, work, and public level 2 had been fully utilized in the 80 mile BEV case.

The number of chargers was only estimated in the case of quick charging. Using simple scaling, one fast charger for every 120 vehicles (246 chargers for 30,000 vehicles) may be needed in the early market and one charger for every 500 vehicles (2000 chargers for 1 million vehicles) could be necessary in a mature market. The number of locations was calculated independent of the number of chargers. A point of diminishing returns was reached after 200 locations indicating that in the early market around 200 locations may be sufficient.

The effect of charging speed at the workplace was tested for both PHEVs and BEVs. For PEHVs level 1 was sufficient in almost all cases over a large range of battery sizes. For BEVs of 60 – 100 miles range, over 70% of chargers at the workplace could be level 1.

The possible effect of charging price was tested for PHEVs showing that in a free charging scenario, PEV owners would get an average of 1kWh – 8kWh of electricity they don’t need from work depending on battery size. Free charging at the workplace has implications for the number of chargers necessary since many people who don’t need charging will nevertheless occupy charging spaces.

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