ITS UCDAVIS
INSTITUTE OF TRANSPORTATION STUDIES

Research Report – UCD-ITS-WP-13-02

Charging for Charging: The Paradox of Free Charging and its Detrimental Effect on the Use of Electric Vehicles

October 2013

Michael A. Nicholas
Gil Tal

Institute of Transportation Studies ◦ University of California, Davis
1605 Tilia Street ◦ Davis, California 95616
PHONE (530) 752-6548 ◦ FAX (530) 752-6572
www.its.ucdavis.edu

Charging for Charging: The Paradox of Free Charging and its Detrimental Effect on the Use of Electric Vehicles

Michael A Nicholas
mianicholas@ucdavis.edu

Gil Tal
gtal@ucdavis.edu

Institute of Transportation Studies
University of California, Davis
1605 Tilia St, Davis, CA

October 22, 2013

ABSTRACT

A survey of plug-in electric vehicle (PEV) owners was conducted focusing on workplace charging suggesting that pricing and a mix of high and low power chargers could efficiently meet the needs of workplace charging and increase electric vehicle miles traveled (eVMT). Respondents reported that in California, 38% of drivers who have chargers at work are unable to charge at least once per week due to congestion at chargers. When asked about price, answers indicated that 4 chargers would be needed for every 10 vehicles if free, versus 1 chargers for every 10 PEVs if the price were double (assuming 1 charger serves 2 cars/day). Since a price of double that of home electricity is still likely to save money, the implication is that people are using free workplace infrastructure 4 times more than they need to. This usage pattern suggests that that simply charging a small fee could encourage more efficient use of infrastructure. If charging is given away for free to spur the market, level 1 or low power level 2 (similar in power to level 1) could be used to install the maximum number of chargers on an existing electricity panel. Level 2 at work could be priced higher to discourage those who don't need it. More dependability for BEVs could encourage their sale and use. In the case of PHEVs, they would only use level 2 when needed or default to a lower power alternative.

INTRODUCTION

Plug-in electric vehicles (PEVs) consisting of both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) are rapidly entering the marketplace and policy makers are seeking ways to increase their sale and likelihood of use. Increasing the availability of workplace charging has been identified as a one strategy to increase the sale and use of EVs and this effort is represented by the EV Everywhere Workplace Charging Challenge [1]. In a recent survey of about two thousand PEV users, the majority report that workplace charging is currently free (Figure 1), but should it be?

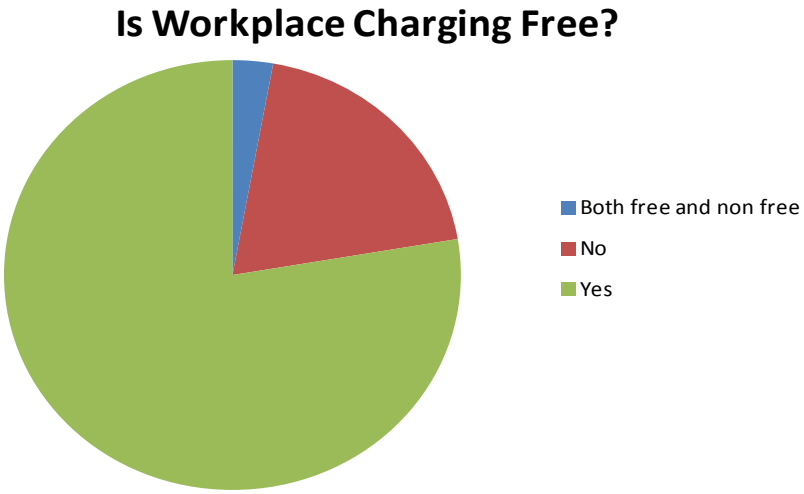

Figure 1 Current workplace charging landscape. 78% of respondents report free charging. Source: UC Davis/CCSE Survey, May-June 2013

While making workplace charging free may increase the purchase of PEVs, there is evidence that free workplace charging does not increase electric vehicle miles traveled (eVMT) for many users versus a priced scenario. Congestion already exists at some chargers, and more effective use of those chargers could enable more eVMT. Early evidence suggests that congestion at chargers is reducing dependability and consequently preventing BEV users from using their vehicle further reducing eVMT. Beyond congestion at chargers, free workplace charging shifts charging from nighttime to daytime which may have detrimental effects on emissions and the electricity grid. This paper is meant to combine recent survey and simulation research to explore this topic and present the pros and cons of free workplace charging.

Pros of free workplace charging

- Potentially increases plug-in electric vehicle sales
- Simplifies charger installation and setup for workplace
- Avoids administrative hassle of collecting revenue
- Avoids impression of pettiness of employer
- Provides employees a workplace benefit

Cons of free workplace charging

- Switches charging from home to work
- Does not appreciably increase eVMT over a priced scenario
- Creates congestion at chargers more quickly than a priced scenario
    - Decreases dependability for BEVs, discouraging certain trips
    - May decrease purchase desirability of a BEV if charging is not dependable
    - Potentially requires expensive panel upgrades to keep up with demand
    - Demand for free chargers may outpace practical installation rates

In the context of these factors, this paper explores using pricing to manage workplace charging; low power charging (<1.5kW) could be priced lower than higher power charging (>3 kW) to encourage efficient use of the chargers. Simulations}[2] and this survey suggest that low power charging could meet the needs of most users if they charge at home. Pricing need not be designed to provide capital recovery on electricity and installation cost, but simply to discourage those who do not require high power charging from using it. Furthermore, if the price for charging rises past about 23 ₵/kWh, it will be cheaper for an efficient PHEV to drive on gasoline. Free charging may still be desirable for a short time during the market launch phase of PEVs, but free charging at work should be restricted to low power charging (<1.5kW at either 120V or 200+V) or other technology that maximizes electric panel capacity. 4-5 times more low power chargers can be installed on the same panel when compared to a higher power 6.6kW charger meaning that more PEVs can be accommodated on the same panel. However, it is likely unwise for charging to remain free at work in perpetuity. If PEVs become a large part of the market, more efficient use of home charging will become necessary, reserving workplace charging for those who need it the most and at the appropriate power level.

LITERATURE REVIEW

There have been a few studies looking at the potential benefit of workplace charging and its potential usage[3,4,5]. Few, however have looked at the effect of pricing on the number of chargers needed and at what power[6,2,7]. Economics, however, suggests that if a resource is free then it will be used more than an equal service that is not free. In the case of EV charging, the choice is often between a home charger at home electricity prices, and a work charger for free. If the work charger is used more often, then more work chargers will be "needed" or at least wanted. To help answer the question of needs versus wants, we asked respondents in a survey how often they would use workplace charging under different pricing scenarios.

Because some charging simulations[6,2] show that low power charging should be sufficient at work for the majority of users, we also asked opinions about low power charging in the survey. The ramifications of the acceptance of low power charging is explored in terms of infrastructure needs at work in the context of pricing.

BACKGROUND

UC Davis – CCSE Survey 2013

UC Davis and the California Center for Sustainable Energy (CCSE) partnered on a survey conducted in May-June 2013 of PEV owners revealing some of the most recent usage of and opinions on workplace charging by vehicle type. Figure 2 shows the prevalence of workplace charging and Figure 3 shows the pricing of current workplace charging based on the results of this survey.

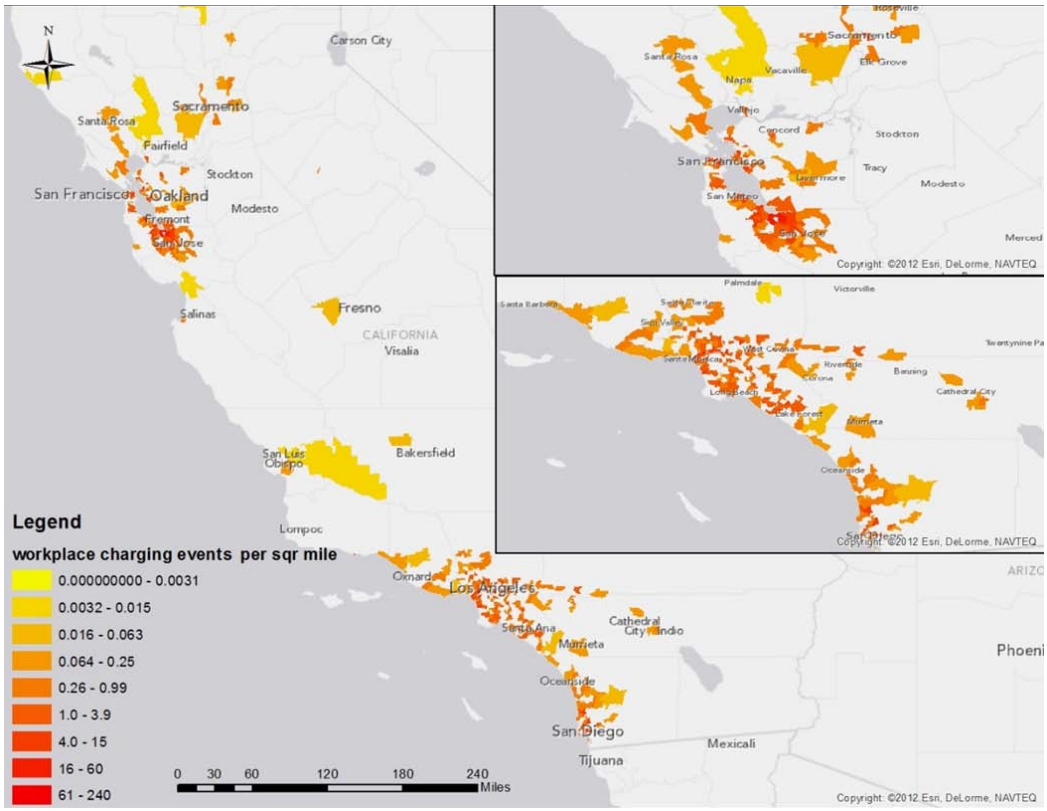

Figure 2 Density per square mile of workplace charging events with a minimum of 5 respondents per zip code.

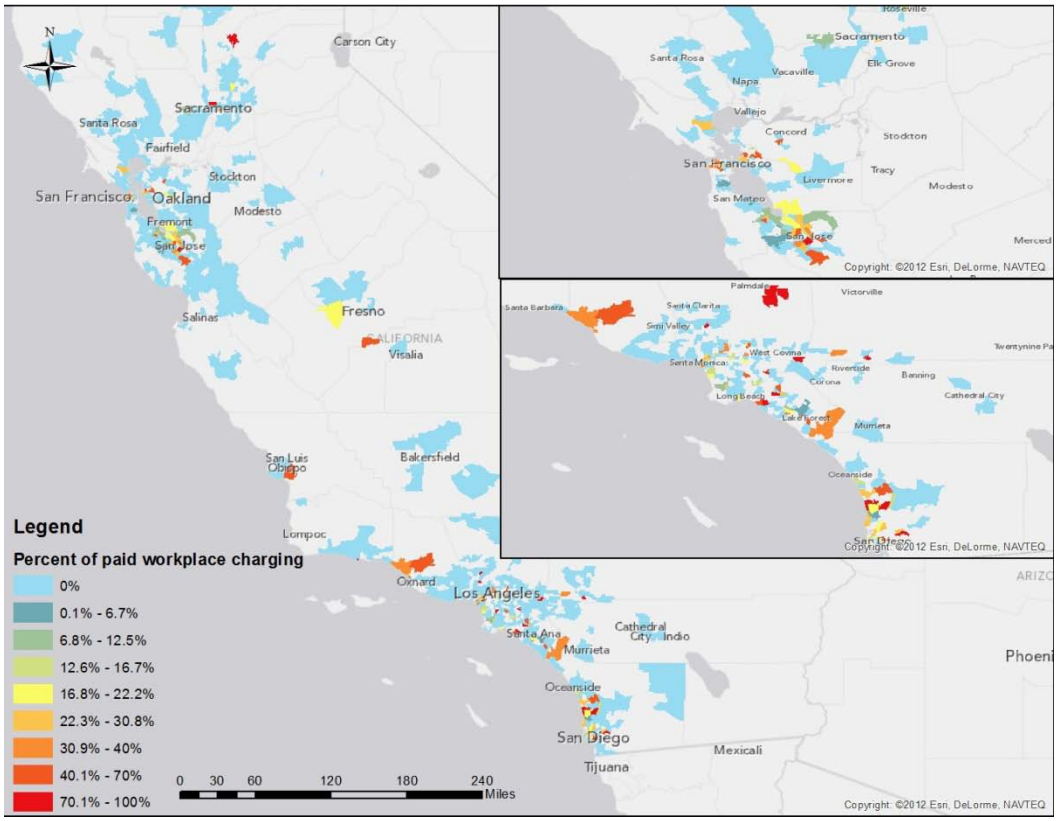

Figure 3 Zip codes where workplace charging was present (no minimum number) and the percent of which was paid and free

Figure 3 shows that there are some areas that do have paid charging, and those light blue shaded areas have exclusively free workplace charging. Although not specifically asked in the survey, most paid workplace charging is likely in public lots near the workplace rather than lots owned by the workplace.

The survey indicates that there is already congestion at work chargers and 38% of those who report workplace charging availability report congestion at chargers at least one day a week. For example, in the San Jose area (Figure 4) on many days people reported not finding chargers reliably at work. Interestingly, the location of the paid charging in Figure 3 in many places is correlates with the congestion shown in Figure 4. What may be happening is a maturation of the charger market and that a strategy to deal with congestion is paid charging. The implication is that if congestion requires paid charging, policy steps may be taken in advance of congestion to improve charger dependability.

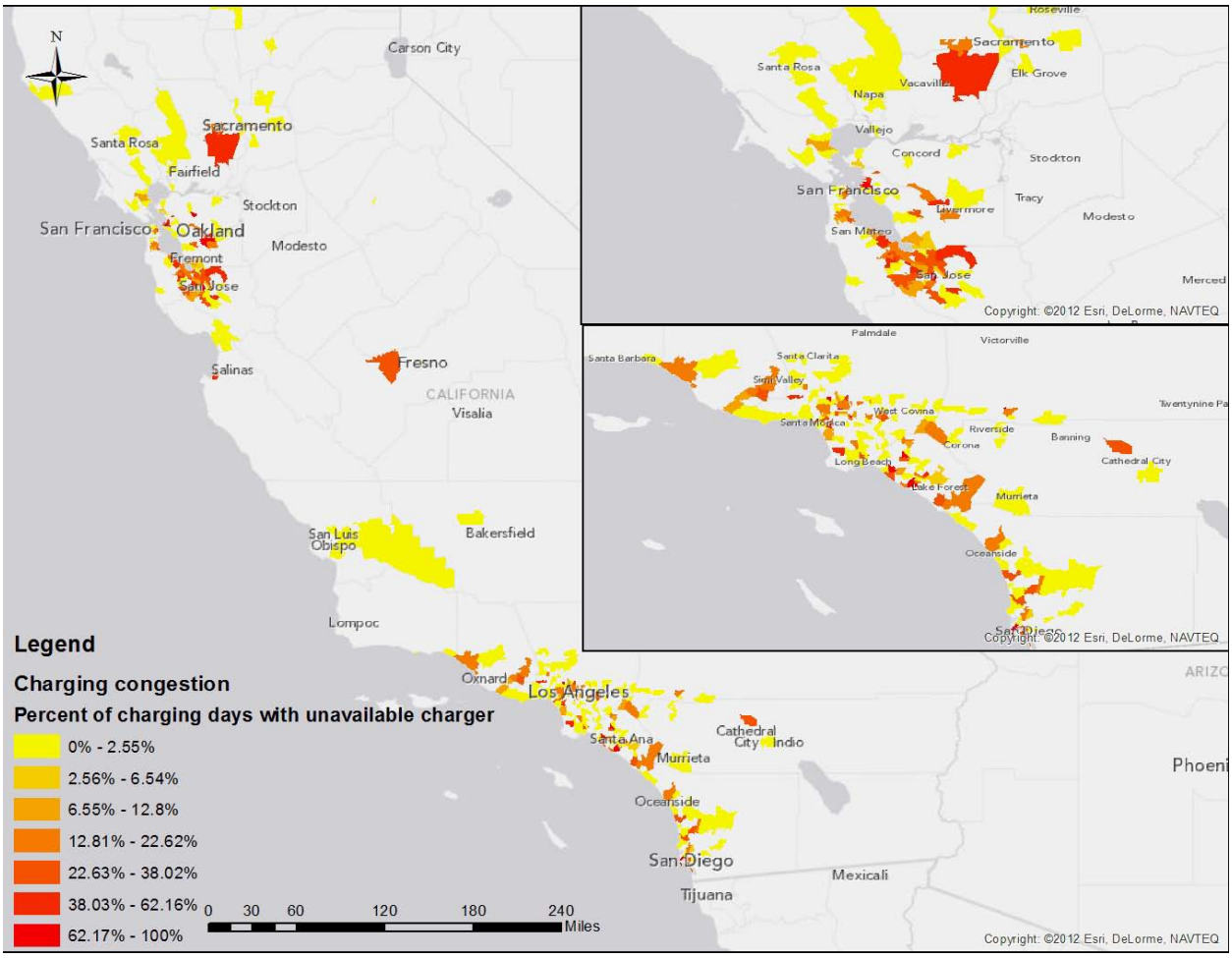

Figure 4 Congestion at workplace chargers by zip code. Minimum 5 respondents per zip code.

Figure 4 shows that charging cannot be depended on reliably at work in many areas. Those who need charging may not be able to find it. In the sections below, further details about the survey and its relation to work charging are presented.

Pros of Free Workplace Charging

Free Charging Increases Vehicle Sales

Free charging does have an initial benefit that should not be understated. Anecdotal evidence suggests that dependable free charging increases vehicle sales. If vehicle sales are the ultimate goal of providing free charging, then a never ending supply of free chargers will accomplish this goal.

We see from respondent comments in the survey that free charging has a strong appeal to make an investment in an electric vehicle.

"Main decision to purchase my Volt was based on my work currently allowing free charging. If they did not provide free charging, I would not have purchased my Volt or other electric vehicle."

However, if the supply of chargers is practically limited by installation and money, eventually, free charging could stifle the market as chargers become more congested and BEVs are not able to depend on being able to charge at work. Because drivers cannot depend on chargers when they need them, the marketability of a vehicle could eventually decrease.

Free Charging is Cheaper to Maintain and Simpler to Administer

There are many reasons employers may have for not charging for charging, these include:

- The cost of electricity is negligible
- There is not an easy mechanism for collecting charging fees to justify the hassle for administration
- The cost of administration is more expensive than the cost of electricity
- Charging creates the impression of pettiness on the part of the employer
- Free charging gives the appearance of corporate sustainability for the lowest initial cost regardless of effectiveness for users

All of these are good reasons, but ultimately, having only free charging may be short-sighted. Oftentimes, businesses go through the hassle of installing chargers only occasionally. Companies may install a few chargers initially, but hiring contractors to install additional chargers is an expensive, time-consuming process. Even though the electricity is cheap, the chargers and installation are not. Free chargers quickly fill up with users regardless of need.

The mechanism to charge money admittedly may be more complicated. Low cost options for a monetary structure do exist, but oftentimes workplaces are not aware of them. Additionally, the fee for charging could be used to recover the cost of administering the fee itself, which has the potential for the system to be revenue neutral. However, whatever the costs may be, they could be small compared to the costs for installing more new workplace chargers. This is an opportunity for policy to direct effort to providing guidelines on best practices.

Cons of Free Workplace Charging

The Big Switch

Evidence from the 2013 survey suggests that users switch from home charging to workplace charging as much as possible if it is free, whether it is needed or not. Taken to its logical extension, free charging creates the situation where chargers are occupied with cars who do not need charging, leaving those who need charging unable to depend on it. Figures 5-7 show three responses to pricing scenarios that illustrate the potential switch from home to free workplace charging. Looking at Figure 5 for the Plug-in Prius, we see that 80% of respondents would plug in four or more times per week if it were free, but only 13% would plug in with the same frequency if it were double the price of home electricity. Similar patterns are observed for the Volt, while Leaf drivers demonstrate a higher willingness to occasionally pay for charging.

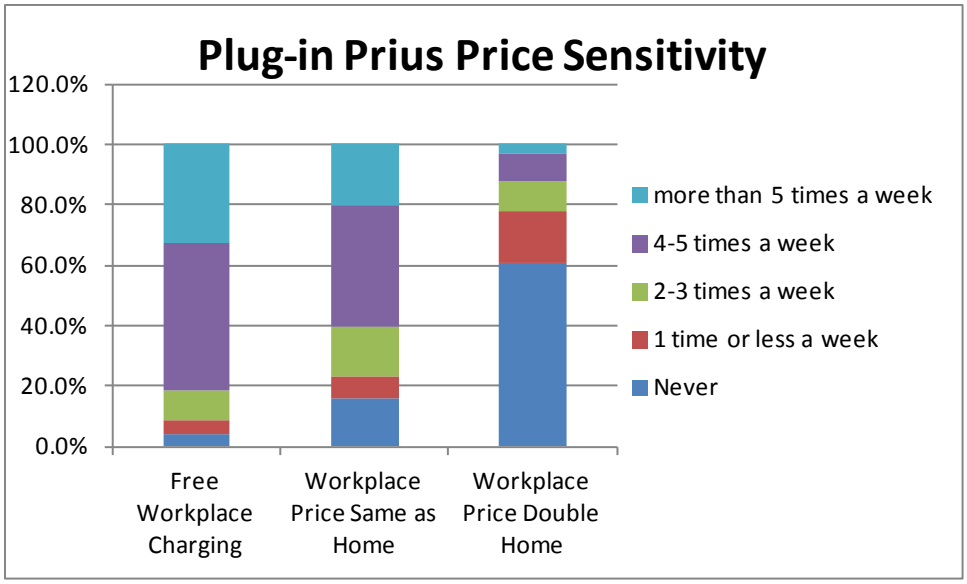

Figure 5 Percentage of Plug-in Prius respondents who would plug in under different pricing scenarios

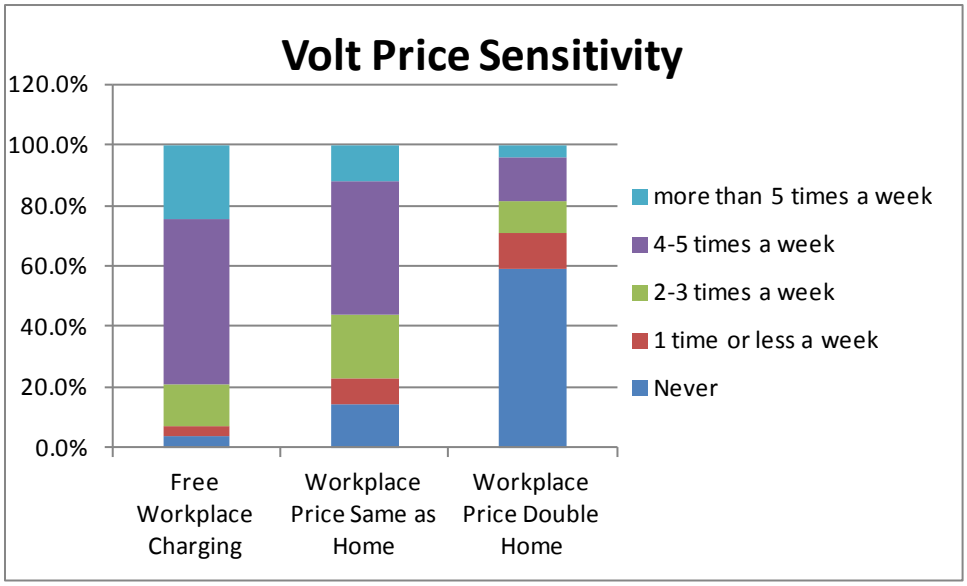

Figure 6 Percentage of Volt respondents who would plug in under different pricing scenarios

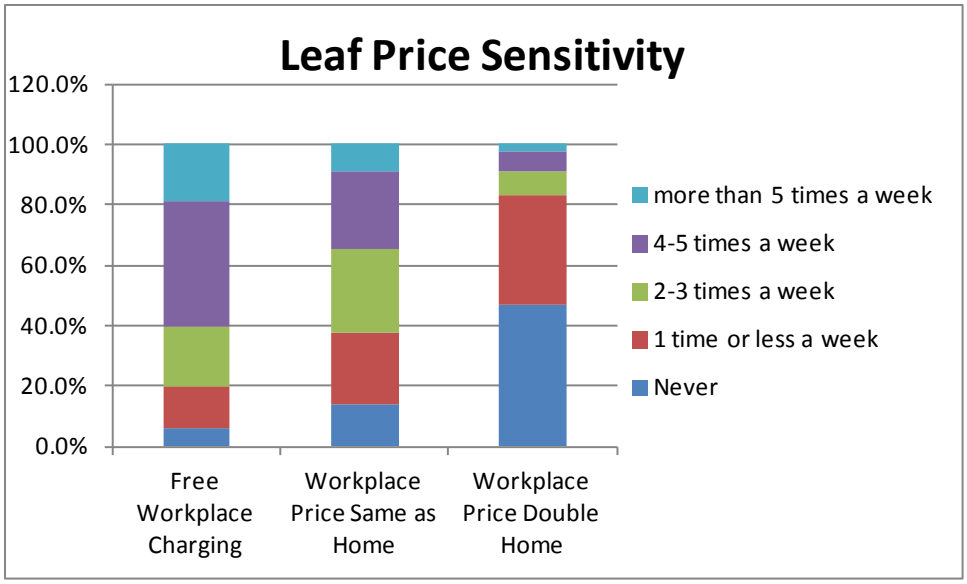

Figure 7 Percentage of Leaf respondents who would plug in under different pricing scenarios

Casting the prices in terms of home electricity was done as a matter of convenience rather than to translate the costs into cents per kWh or cents per mile. However, phrasing the question this way is meant to highlight one parameter: will consumers plug in at home or at work? Each of the three pricing scenarios has a unique rationale: free workplace charging represents the economic incentive to arbitrage electricity prices; equal pricing represents how many people could get meaningful benefit for the inconvenience of plugging in; doubling the price represents how many people need the charge to either return home or save money on fuel costs. Since price parity on a cents per mile basis is about 23 cents per kWh for a Prius assuming $3.66 per gallon gasoline, driving on gasoline may be the rational choice in certain pricing scenarios.

Free Charging Could Quadruple Usage and Drive Up Infrastructure Costs

Ultimately the switch from home to free workplace charging creates two problems: vehicles are charged in the day versus the night (creating the potential for grid stress or increased emissions) and providers of workplace infrastructure should expect to need 2-4 times the number of chargers they would need under a priced scenario. Oftentimes, a large number of chargers requires costly upgrades that might otherwise be avoided. As an example, using the preferences above assuming a fictitious U.S. market of 33% Plug-in Prius, 33% Chevrolet Volt, and 34% Nissan Leaf we can make some representative calculations on the number of chargers and possible investment required in different scenarios. Assuming that a Level 2 charger can serve on average of 2 cars per day and drivers charge with the frequency in the free scenario above, 41 chargers would be needed per 100 vehicles. With a price equal to home, 32 chargers would be needed. With a double-priced scenario 11 chargers would be needed. These estimates will double if only one car per day uses the charger.

Free Charging May Decrease Dependability for BEVs

Dependability is an important factor when deciding to buy or use a BEV. The range of the vehicle limits what driving can be done but charging can address some of these limitations and give confidence to the driver that he or she can complete a journey. When deciding to buy a vehicle, customers may consider

dependable charging as a factor in whether a BEV will meet their travel needs, and in turn influence their purchase decision. Dependable charging also affects the use of the vehicle on any particular day. On longer travel days, if there is a doubt as to the ability to complete a trip with a BEV, then a gasoline vehicle may be chosen – if another vehicle is even available.

We see evidence of the importance of dependable charging in Figure 8 by comparing the willingness to pay for charging at double the cost of home electricity.

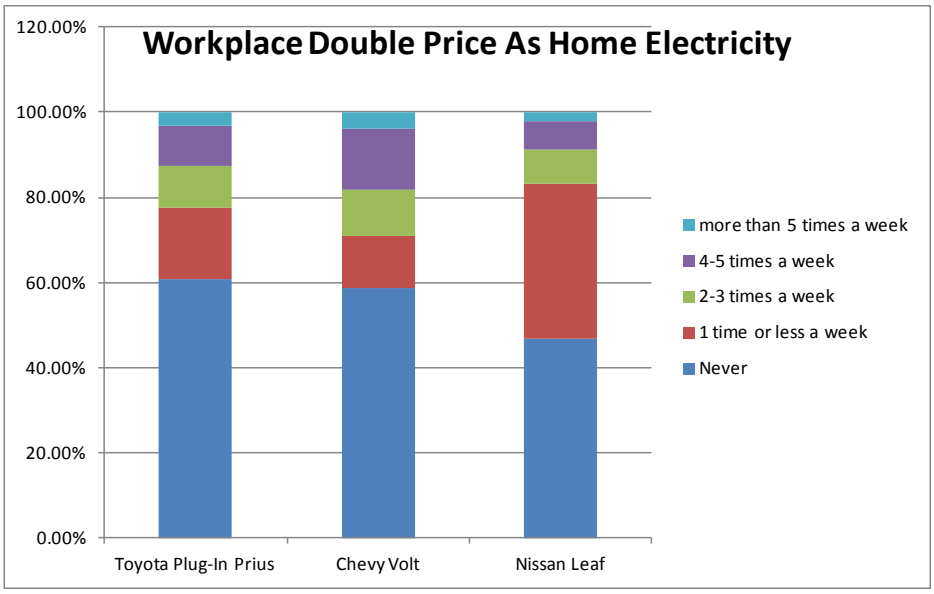

Figure 8 Expected charging frequency assuming workplace charging were double the price of home electricity.

One of the most striking features is the willingness of Leaf drivers to occasionally (1 time or less per week) pay double for charging relative to the other vehicle types. This makes sense since Leafs have few options on longer travel days other than to charge to complete their trips. In this case, dependability of charging is of higher value for BEVs than for other vehicle types. This suggests that a charging fee may actually help Leaf or other BEV drivers.[1] However, another interesting finding from survey responses is that less than 20% of Leaf owners would charge more than once per week. Overall, these two points combined imply that Leaf owners would need fewer chargers at workplaces than other vehicle types, preferring to charge at home in normal circumstances. These chargers, though, need to be more dependable in terms of their availability.

The comment below highlights two issues related to dependability: chargers are getting congested (possibly because they are free), and that dependable workplace charging is important in extending the range and functionality of the vehicle.

[1] Additionally, improved dependability of workplace chargers can benefit PHEV owners who do not have access to home charging. In this case, charger availability is doubly important. If those who do not need the charging are using the chargers, PHEVs who have no other source of charging may be forced to run on gasoline.

"In the time I've had the Leaf, the infrastructure has gotten much better. In the past year my employer installed 12 free level 2 chargers. That really was a game changer for me extending my practical range and allowing me to be far more liberal with my use of the heater in the winter. At first I was the only one using any of the chargers. Now they are almost always occupied. Parking services is looking into a 4 hour time limit for charging which seems fair. "

Although not specifically stated, the comment above highlights that employers may have many chargers fill up very quickly if the charging is free. Another commenter directly states that reliability is becoming an issue

"The charging infrastructure and reliability and availability have been lacking and is becoming more scarce due to the growing number of Plug in hybrids."

Another Leaf commenter shows the willingness to pay for dependability up to the price of gasoline.

"As for what I would pay, I'd pay as much as gas prices if chargers were everywhere just so I don't have to worry about not having the ability to charge my car. I would only use it in an emergency or long road trips but I'd pay that amount to be able to use my electric car more. I love my car! We have a 4 year old and had twins right after buying the car and we use it exclusively to drive the family around. We like to say we fit everything but the nanny in the Leaf!"

Free Workplace Charging May Not Increase eVMT

The survey responses are consistent with previous research findings using models. Modeling California travel behavior also reveals that there may be little benefit, in terms of eVMT, to giving away charging versus charging for it if home charging is available. In a study by Nicholas, Tal and Woodjack[2] The travel survey responses from about 15,000 households in California (using ~30,000 gasoline vehicles) were used to determine how well various PHEVs and BEVs would be able to complete statewide travel assuming workplace charging. Three pricing scenarios were run (Figure 9): free, same as home electricity, and double the price of home electricity.

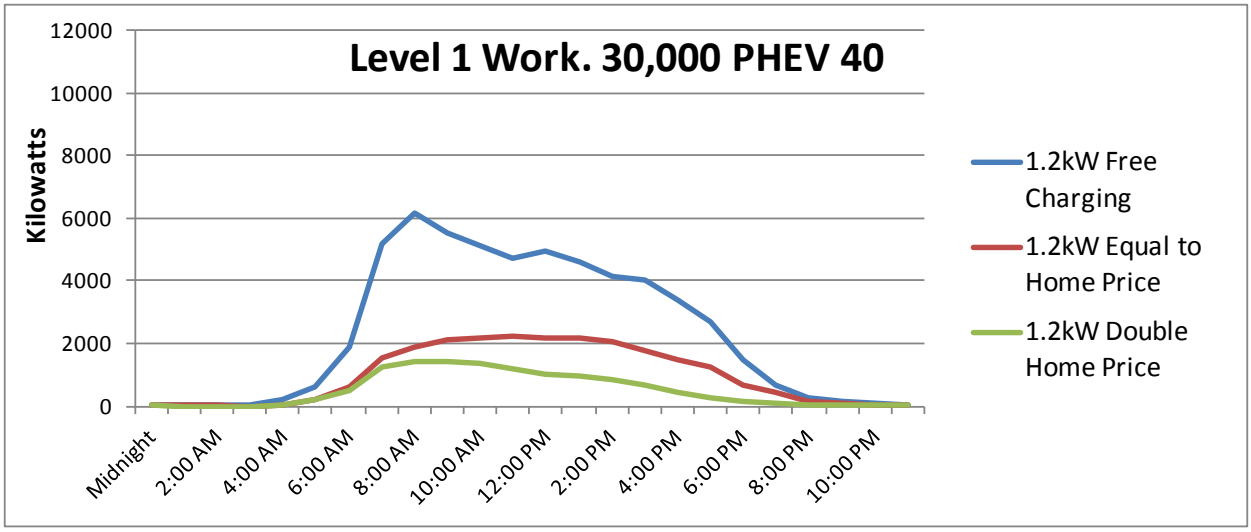

Figure 9 Modeled results of workplace charging under free and priced scenarios for a 40 mile PHEV.

All three scenarios result in the *same eVMT*, but more power is taken from work in the free scenario. The results above are in terms of kilowatts, but the number of chargers needed would be greater in the free scenario with *no societal benefit in terms or eVMT*. Additionally, the scenarios above likely underestimate the workplace charger usage since all vehicles are assumed to start at home with a full charge. In reality, we see consumers stop charging at home when possible and only charging at work.

Additionally, from survey comments we can see how free charging may not necessarily increase eVMT. The PHEV driver below shows a willingness to plug in if it's free, but does not really need it.

> "I think ubiquitous chargers are mostly important for EV owners because of range anxiety and even then level 2 chargers are just not fast enough, but not so much for PHEV owners, who simply don't suffer from range anxiety. Having said that, if my company had (free or mostly free) charging stations in their parking lot (in reasonable locations), I would probably hook my car up to them every day. Currently my commute is short enough that I don't really need that, but it is possible that the company might move (or I might) further away, in which case workplace charging would be nice."

Interestingly, the driver knows that BEVs need charging, but with no signal as to the value of the charging to someone else, will "probably hook up my car everyday", possibly edging out the very people he cites as needing it. Also, the driver's work may move farther away and he would like the option to charge. Ironically, those chargers may be full of people who will "not really need it."

RECOMMENDATIONS

Low Power Charging is Sufficient for Most Vehicles

The simulations shown in Figure 9 also show that low power charging is sufficient for most vehicles. When high power 5.7kW chargers were compared to low power 1.2kW chargers, the benefit in terms of modeled statewide eVMT was never more than a 1% increase for any size PHEV. For larger battery size BEVs, the benefit of high power level 2 charging at work was an approximate 2% increase (double that of PHEVs) in eVMT over low power charging. The modeling shows that for BEVs, approximately only 20% of chargers need to be high power level 2 to provide additional benefit to drivers.

From survey responses about low power charging (Figure 10), we see that about 30% of people disagree or strongly disagree that "Level 1 charging at work is sufficient for my needs." However, about half agree that low power charging is sufficient at work. The modeling suggests that 80% of chargers could be low power and the surveys support this by showing that low power charging could meet 50%-80% of consumers charging preference.

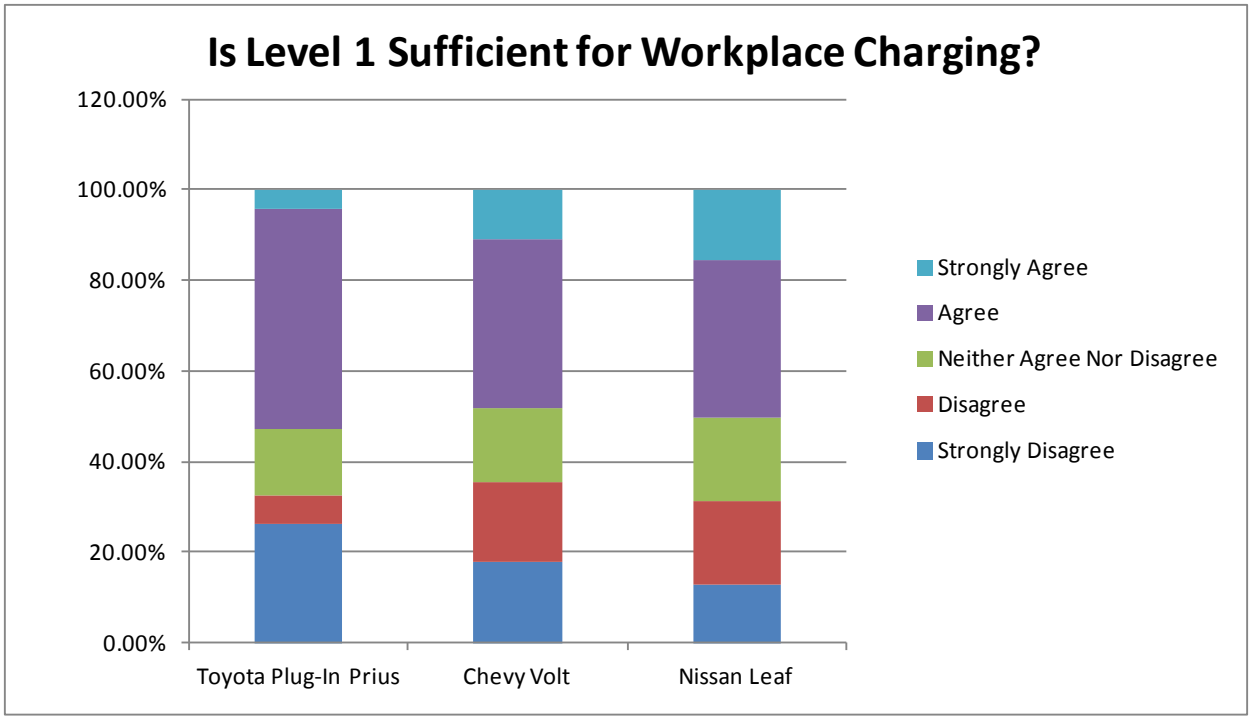

Figure 10 Survey responses to the sufficiency of low power charging at the workplace show that many agree that low power charging is sufficient.

Sufficiency can also be viewed in terms of the power possible to gain in an 8 hour workday with low power charging. Assuming a lower power 1.2kW charging rate for 8 hours, 9.6 kWh of energy can be gained in a day. In a Leaf, this translates to 29.2 miles, enough to return most people home, as the median one way commute for survey respondents is 14.6 miles. 90% commute less than 35 miles.

How Much to Charge?

How much should be charged at work to ensure the efficient use of chargers? To preserve the economic benefit of driving on electricity, charging should be priced between average home electricity price and the

price of gasoline. Low power 1.2kW chargers could be free to 15₡/kWh (approx 12₡/hr) and high power 6.6kW chargers could be priced at 15₡ to 23₡/kWh (approx. $1-$1.50/hr). These prices are not meant to provide capital recovery or even recovery on electricity, but to encourage drivers to make better use of home chargers if available. If charging were priced at the home rate of 15₡/kWh then there would be no incentive to charge at work unnecessarily. Some have an EV home rate of as low as 6₡/kWh and so at a 15₡/kWh price, drivers would have little incentive to charge at work. However, as shown in Figure 11, even a Prius would save money up to a price of 23₡/kWh at work.

Figures 2-4 show that 80% of drivers would use a free charger daily, but only 20% would use it daily if it were priced double that of home electricity. Factoring into these choices is commute distance, battery size, home electricity price and gasoline price. Singling out which factors are responsible for the choices is difficult, but Figure 11 puts the last 2 factors, electricity price and gasoline price into context for different car models on a cents per mile basis.

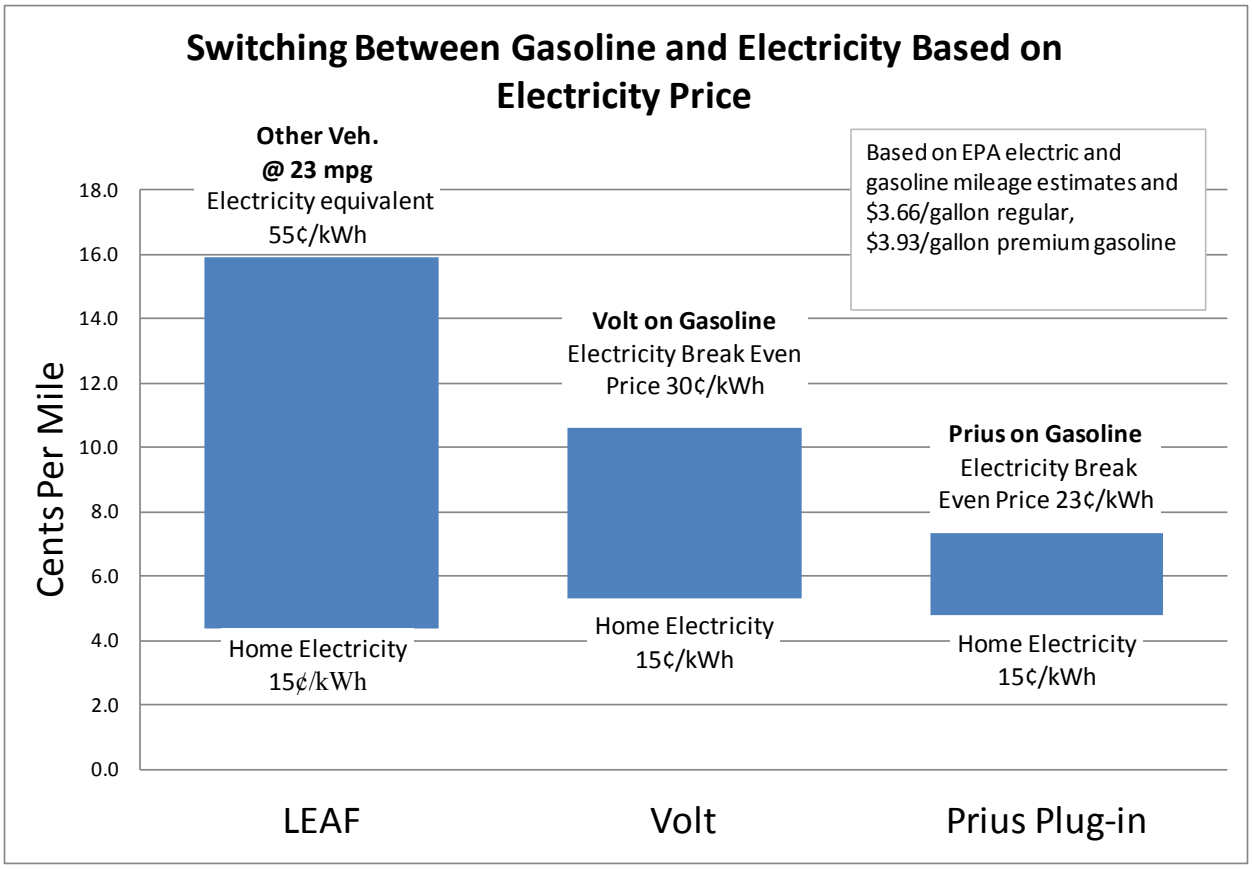

Figure 11 Electricity breakeven price points when arbitraging electricity against gasoline[8].

For the Plug-in Prius, the range of prices above home electricity (>15₡) and below the break even gasoline price (23₡) is smaller than for other vehicles. Also the battery is smaller, so the benefit of plugging in can be very small. To fill an entire battery at 4.4 kWh, the user can save about a dollar versus driving on gasoline if the charging were free, if the driver were paying home electricity prices, then the savings over driving on gasoline are 32₡ per charge event. The situation is different for the Volt. If charging were free, then to fill an entire 13kWh battery, this saves $3.90 over driving on premium

gasoline. If paying the same as home electricity, the owner saves $2.10 over driving on premium gasoline.

Currently public paid level 2 chargers are charged by the hour. They typically range from $1-$2/hr. At 6.6kW, $1/hr equates to 15¢ per kWh. This penalizes vehicles that do not have the ability to draw a high rate of power, but encourages efficient use of the infrastructure.

CONCLUSIONS: INITIALLY FREE LOW POWER CHARGING AND FEE BASED HIGH POWER LEVEL 2 CHARGING

Free charging provides the benefit of increasing sales, but the disbenefits of shifting charging from home to work, and creating congestion at chargers. Because of this, some amount of free charging may be desirable to initially spur the market. However, this paper suggests that low power charging at about 1.2-1.5 kW is sufficient for most drivers on most days and if free charging is given away to stimulate the market, that this power level is sufficient. To create dependability in the system for those vehicles that need higher power, pricing at a rate higher than average home electricity, but lower than gasoline cost could be used for higher power chargers such as 6.6kW.

Pricing is not a strategy to make money from employees, but rather to make efficient use of chargers. Cost recovery on installation and electricity need not be the goal, simply enough to encourage the efficient use of infrastructure relative to home charging.

Because free charging spurs the market and a growing market is generally seen as positive, free low power 1.2-1.5kW charging could provide a path for workplaces to install many chargers and avoid costly panel upgrades while still providing charging to their employees. Dependability for BEVs increases if paid higher power level 2 charging were available because those who don't need high power level 2 charging will favor low power chargers.

Other strategies that don't require charging a fee can be used in this scenario as well. Time limits on high power level 2 chargers can be instituted versus no time limits on low power charging. This is a low cost strategy, but may still result in a shift from nighttime charging to daytime charging and create congestion were it might otherwise be avoided.

There are some limitations to the pricing suggestions in this analysis. The price for home electricity is based on a tier system in many parts of the state making home electricity price variable. Since PEVs use a great deal of electricity, the price of home electricity may be high if charged at home and the user does not have a special EV rate. EV rates should help a PEV owner reduce costs of off-peak electricity, but there are some cases when any load added to a home is expensive. I this case there may be some difference in the assumptions vs. the actual price of electricity and corresponding behavior. However, it is believed that pricing will still create an efficient use of chargers.

If high power level 2 chargers are consistently available, drivers can depend on them. In the case of BEVs, this is especially important as higher power can at times mean the difference between being able to complete a journey or not. BEVs become much more viable as a transportation choice and this increased dependability could increase sales similar to the increase caused by free charging.

REFERENCES

1 US Department of Energy. 2013. *Ev Everywhere Workplace Charging Challenge*. Accessed May 21 2013. Available from http://www1.eere.energy.gov/vehiclesandfuels/electric_vehicles/workplace_charging.html.

2 Nicholas, Michael, Gil Tal, and Justin Woodjack. 2013, January. California Statewide Charging Assessment Model for Plug-in Electric Vehciles: Learning from Statewide Travel SurveysDavis, CA: University of California, Davis. Institute of Transportation Studies, UCD-ITS-WP-13-01.

3 Weiller, Claire. 2011. Plug-in Hybrid Electric Vehicle Impacts on Hourly Electricity Demand in the United States. *Energy Policy* 39, no. 6: 3766-3778.

4 Traut, Elizabeth, Yimin Liu, Chris Hendrickson, Jeremy J. Michalek, and Erica Klampfl. 2011. Optimal Design and Allocation of Electrified Vehicles and Dedicated Charging Infrastructure for Minimum Greenhouse Gas Emissions. In *Transportation Research Board Conference*. Washington DC.

5 Davies, J., K.S. Kurani, and Davis. Institute of Transportation Studies University of California. 2010. *Households' Plug-in Hybrid Electric Vehicle Recharging Behavior: Observed Variation in Households' Use of a 5kwh Blended Phev-Conversion*: Institute of Transportation Studies, University of California, Davis.

6 EPRI. 2012, Guidelines for Infrastructure Planning: An Explanation of the Epri Red Line/Blue Line MethodPalo Alto, 1024102.

7 Bosman, Craig. 2013, The Future of San Francisco's Public Electric Vehicle Chargers: Goldman School of Public Policy, UC Berkeley.

8 DOE. 2013. *Fuel Economy*. Accessed June 13 2013. Available from www.fueleconomy.gov.