Pricing Workplace Charging: Financial Viability and Fueling Costs

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ABSTRACT

Overnight home charging is expected to be the most prevalent and cost-effective way to refuel plug-in electric vehicles (PEVs). Workplace charging is also expected to play a prominent role and provide various benefits, such as extending the number of electric miles driven and enabling PEV adoption by drivers in difficult residential charging environments.

This research assesses workplace charging from two perspectives, 1) employers investing in workplace-charging facilities and pricing their use and 2) employee drivers. It finds that pricing levels likely to provide drivers with financial motivation to fuel at work relative to gasoline refueling might provide limited opportunity for station cost recovery. For example, a $0.20-per-kilowatt-hour markup on top of average commercial electricity costs—a level some drivers may even find uncompetitive—might only cover $1,500 in all-in facility investment costs per PEV served. Similarly, drivers may balk at workplace-charging prices at or exceeding $1.25/hour or $35/month, which provide comparable cost-recovery potential. Additionally, the differential, “discriminatory” impact of different pricing structures is discussed.

Across pricing structures, increasing facility utilization (i.e., increasing economies of scale in use) is key to improving financial viability. This might prove difficult, however, given associated costs described herein. Solutions that increase utilization while minimizing per-vehicle costs (e.g., “multiplexed,” perhaps lower-power facilities) might help address these constraints.

Monte Carlo simulation is presented to highlight key uncertainties of both station profitability and refueling costs. Importantly, it indicates that employers’ choice of pricing structure will differentially affect their ability to remain financially viable in the face of uncertainty.

Keywords: plug-in electric vehicle, workplace charging, pricing, recharging costs, profitability, cost recovery

1 INTRODUCTION

1.1 Background, Objectives, and Article Structure

Overnight charging at home is expected to be the most prevalent and cost-effective way to refuel plug-in electric vehicles (PEVs) (*1*). Workplace charging is expected to play the next most prominent role. This is due to factors such as long and regular vehicle residence times (*2*), the daily importance of the commute to drivers, and the strong influence the commute has on drivers’ travel behavior and their ability to maximize the potential air-quality, energy-security, and greenhouse-gas-emissions benefits of PEVs. The presence of workplace charging enables drivers with plug-in hybrid EVs to multiply the number of electric miles driven per day, extends the reach of all-battery EVs, and might enable drivers in difficult residential charging environments to enter the PEV market.

Nevertheless, the implementation of workplace charging remains challenging as stakeholders wrestle with this relatively new phenomenon and its potential costs and benefits in a wide variety of contexts. Site hosts, regulators, and consumers lack information needed in order to understand the costs of fueling and implications of various pricing and incentive policies. The supporting literature is relatively sparse and nascent. For example, business models for recharging have been discussed from the perspective of market structure and actors (*3, 4*). Financial analysis by Schroeder and Traber examined public fast charging stations (*5*), which use different technology with different considerations than examined here. Botsford (*6*) analyzed non-residential charging from a cost-based perspective that articulates what revenues are required to cover examined costs, the opposite approach to the one taken below for workplaces.

This research assesses workplace charging from two perspectives: i) employers investing in workplace-charging facilities and pricing their use and ii) employee drivers. These perspectives are explored in turn in each of section 2 (methods and assumptions) and section 3 (results and discussion). This analysis makes several contributions, including:

1. finding limited opportunity for employer cost recovery per vehicle served at prices that employee drivers might find financially motivating,
2. describing opportunities for increasing financial viability through economies of scale in use,
3. characterizing each of three pricing structures for their differential impacts on drivers with varying commute and vehicle characteristics,
4. describing how choice of pricing strategy affects employer ability to remain viable in the face of uncertainty, and
5. providing benchmarks that facilitate comparison of pricing levels both across pricing structures and relative to two gasoline refueling baselines.

2 METHODS AND ASSUMPTIONS

2.1 Workplace-Charging Financial Model Elements

This subsection describes the major elements of the financial model developed to examine workplace-charging investments from the employer perspective, including costs, financial assumptions, and facility utilization.

2.1.1 Costs

Charging station costs can be broken into three types: upfront, periodic, and variable costs. Costs often vary dramatically based on site-specific conditions, and not all costs are required for all installations.

Upfront costs include the fully-burdened cost of the facility and its installation, including:

1. PEV-ready electrical service
   (e.g., site assessment and design, electric-service upgrades, permitting, trenching, conduit);
2. parking/“station” modifications
   (e.g., accessways, bulwarks, signage, security, access control, data logging if separate from the charger);
3. electric-vehicle supply equipment (EVSE)
   (e.g., chargers with various configurations of power level, number of outlets or vehicles served, cabling, access controls, network access capability, data logging); and
4. facility decommissioning

Variable costs (e.g., electricity energy and demand charges, rate-tier adjustments, sales tax, facility operation & maintenance) relate to the amount of charging provided (e.g., per kilowatt-hour [kWh]). Periodic costs are ongoing but relate less closely to the amount of service provided (e.g., property tax, insurance, periodic access or network fees, facility management and data processing). They can be treated as an additional upfront, fixed lump sum if their level is known.

Because of the wide variety of facility cost structures (the subject of future work) and in order to allow flexible exploration of a variety of cost levels, the financial modeling employed herein explicitly presents a range of "all-in" fixed investment levels (e.g., the vertical axes in Figure 3-1). This allows the reader to choose different levels (i.e., pick different points) appropriate to different situations, as described in subsection 3.1. For illustrative purposes, consider the following estimates, which are not meant to be representative of a full range of possible situations, but rather are presented to help calibrate the reader as she considers her own specific situation/context of analysis.

Fixed Costs (Upfront and Periodic) The California Plug-in Electric Vehicle Collaborative (CA PEVC) indicates that workplace-charging installations might typically cost on the order of $5,000 per 240-volt (240V) installation, plus the cost of the charging equipment (*7*). The cost of the charger also varies based on level and features. For example, Southern California Edison estimates Level 1 (120V) charging equipment ranges $100–1,000, Level 2 (240V) $500–6,000, and DC fast charging equipment tens of thousands of dollars (*8*).

Networked chargers might require additional periodic costs, e.g., ~$200 per year per charger, including some level of vandalism cleanup (*9*). Non-networked code-restricted access systems (with the option for drivers to use their own phone network to pay and receives codes) might have lower periodic fees and other costs (*10*).

Lower-power (e.g., Level 1 systems typically providing less than 2 kW of power and incorporating common outlets) and/or multiplexed charging equipment serving more than one vehicle per off-board charger might further lower costs beyond the standard one-Level-2-charger-per-vehicle approach that has dominated thus far.

Variable Costs Within a reasonable range of utilization, electricity costs are expected to dominate the variable cost category. Electricity costs vary based on utility territory, business class, total energy and power demanded, season of year, time of day, and rate schedule selected. For simplicity, it is assumed that variable costs average $0.1275/kWh[1] [the average retail price of electricity sold in 2011 to commercial customers by the Los Angeles Department of Water and Power (*11*)].

For the purposes of uncertainty analysis, it is assumed variable costs range from a low of $0.09/kWh [the average 2011 price for Southern California Edison (SCE) industrial customers, (*11*)] to a high of $0.30/kWh [the peak penalty price for charging during the summer between the hours of noon and 9pm on SCE's time-of-use PEV charging schedules for small and medium commercial customers (*12*)].

2.1.2 Financial Assumptions

Unless otherwise stated, the financial modeling described here evaluates the present value of charging revenues net of all-in investment costs assuming: a ten-year planning horizon, a 5% discount rate, a 3% annual growth rate in electricity and gasoline prices and the level of markup, and maintenance costs equivalent to 5% of total costs. Taxes and revenue sharing with network providers are not treated explicitly here, and thus can either be considered to be 0% or covered in fully-burdened fixed costs.

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[1] This assumption ignores the possibility that energy purchased to charge PEVs could move the business into a more expensive tier of electricity prices and/or that the power demanded by the equipment could add to the facilities' demand charges (if applicable). This is probably a reasonable simplification for a small number of vehicles served relative to the workplace's overall electricity consumption and with a little care not to allow PEV charging during the hours each month when the facility demands its peak amount of power (upon when demand charges are set). Further, utilizing special EV rates (possibly requiring the purchase of a second meter to be included in "all-in" installation costs) may also avoid these possibilities.

2.1.3 Facility Utilization

Variable costs and revenues depend on the level of use experienced by the charging facility. Electricity costs and per-kWh revenues depend on the amount of energy consumed, and per-hour revenues depend on the charging duration. These are in turn a function of the power (kW) of the charging equipment, and the amount of energy (kWh) required. For simplicity, several assumptions are made, including that the vehicle will draw power until it is fully charged, that the power drawn is constant, and that it amounts to approximately 3.5 kW for Level 2 charging (*13*).

The amount of energy required is dependent on the state of charge of the vehicle when it plugs in at work, which, for a given electricity consumption rate (see below), depends largely on the daily commute distance. The daily commute distance is assumed to average 30 miles per day (*13*). In order to calculate how many kWh will be needed to recharge PEVs that have traveled, on average, half of that daily commute distance (15 miles), the vehicle's electric fuel economy is needed. It is assumed that the average PEV can make the trip in electric mode consuming electricity at approximately 35 kWh/100 miles. This is an average calculated using the U.S. Environmental Protection Agency's adjusted electric economy ratings for PEVs, weighted by aggregated sales data through April 2013 (*14*).

Thus, to recover from a 15-mile one-way commute, the workplace charging facility needs to provide 0.35 kWh/mi or 5.25 kWh per vehicle. At the 3.5-kW Level 2 charging rate, this would take approximately 1.5 hours. It is further assumed that the charging equipment will be utilized 5 days per week for 48 weeks out of the year, or 240 days per year.

2.2 Fueling Decision Support for Employee Drivers: Additional Inputs

Additionally assumed are a sales-weighted, EPA-rated PHEV average gasoline fuel economy of approximately 41 miles per gallon (mi/gal) and a conventional-vehicle fuel economy of 27.2 mi/gal. The former was calculated based on PEV sales and the latter is the EPA composite rating for small and medium cars in model year (MY) 2011, the most recent year for which data was available (*15*). This is a higher, and therefore more conservative, fuel economy than the composite ratings for both MY2011 cars as a whole (25.9) and all passenger vehicles (including trucks, 22.8). At the moment, PEVs are mostly small and medium cars, but the alternative fueling option available to some PEV drivers might be a larger car or truck. In all cases (including PEVs), the ratings used herein are EPA "adjusted" to better reflect real-world driving conditions (i.e., the number used on the new-vehicle sticker).

3 RESULTS AND DISCUSSION

3.1 Investment and Pricing Decision Support for Employers

Figure 3-1 plots cost-recovery breakeven points as a function of "all-in" investment cost levels (vertical axis) and fee levels (horizontal axis). On the breakeven lines, the 10-year present value of net revenues (NPV) is zero and costs are recovered. Above the breakeven lines, the NPV is positive and the workplace-charging investment is potentially profitable. The figure allows exploration of individual situations seen by firms at specific locations with varying conditions. Additionally, it allows exploration of the effect of incentives that change cost levels, a subject of future work.

It should be noted that the only revenues represented in Figure 3-1 are those from fees for recharging services. Other sources of revenue or broader benefits might be available, including from tax and accounting benefits, participation in utility demand-response programs, and future value streams from the intelligent control of charging rates to provide various types of grid services [e.g., participation in regional grid markets like regulation, benefits to utility operation and the transmission or distribution system, customer-side-of-the-meter benefits like utility-bill mitigation or power quality/reliability, and/or a variety of related renewable-integration services (*16, 17*)]. Eventually, workplace-charging systems might be upgraded to broker bi-directional power flows to and from PEVs for greater levels of grid services, onsite energy management, and emergency power.

Figure 3-1 has three parts (a–c) presenting the NPV resulting from three basic price structures: per-kWh (a), per-hour (b), and per-month (c). Per-kWh scenarios indicate the amount of the initial markup added to the electricity costs passed on to the driver. Per-hour (b) and per-month (c) scenarios indicate the level of those fees. The first of the four data markers in each case indicates the break-even level required to cover variable (electricity) costs only (i.e., zero project costs). For example, in part a, charging for the electricity with no additional markup precisely covers electricity costs, resulting in a net present value of zero. \$0.50/hour and \$15/month are rough equivalents, given electricity costing \$0.1275/kWh. The next data markers represent symmetrical increases in the fee level for illustration, up to levels that might represent reasonable maximums that drivers are generally willing to pay. As will be seen in section 3.2, the third marker might still provide the driver with some advantage over fueling on gasoline at today's prices, whereas the fourth marker might be considered uncompetitive with gasoline, on the whole.

In general, it appears difficult to recover more than a couple thousand dollars of investment on one charging unit providing one modest charge per day on a limited number of commute days per year. It is clear that, for those workplaces concerned with profitable operation of their workplace-charging facilities, increasing utilization and/or reducing average unit costs is important. These topics are explored in subsection 3.1.2 and future work. However, some workplaces may nevertheless face high fixed costs of installation and may not be installing many charge spots over which to spread them. Similarly, they may face pressures that have the effect of limiting the number of vehicles served per day. Unlike accommodating early-adopter workplaces, some workplaces:

1. may not wish to require the potentially productivity-decreasing process of moving cars in and out of charging locations throughout the day;
2. may wish to limit or prohibit charging in the afternoon to avoid peaks in either energy charges or facility demand charges; and/or
3. may not have synergistic opportunities to open their charging to fleet or public vehicles after employee charging (and peak hours) take place.

Figure 3-1 also shows the effect of an additional \$1 fixed fee per session (dotted lines). This addition increases the cost-recovery potential per vehicle of a given simple fee structure by \$1,000–\$1,500. Similarly, the workplace might be tempted to confound parking and recharging pricing in such a way that the PEV driver continues to pay a rate higher than normal parking fees for occupying a recharging space after active recharging is completed. However, for reasons discussed here and elsewhere (*18*), fixed-fee structures are potentially both less transparent and more discriminatory against certain vehicle types and drivers. For example, for those with smaller batteries and/or shorter commutes, the large fixed component of these fee structures can, in one manifestation or another, quickly end up raising the effective costs of workplace charging to several dollars, not several cents, per kilowatt-hour received. This might be counterproductive to adoption of workplace charging by the majority of the PEV market that drives PHEVs or neighborhood electric vehicles (NEVs).

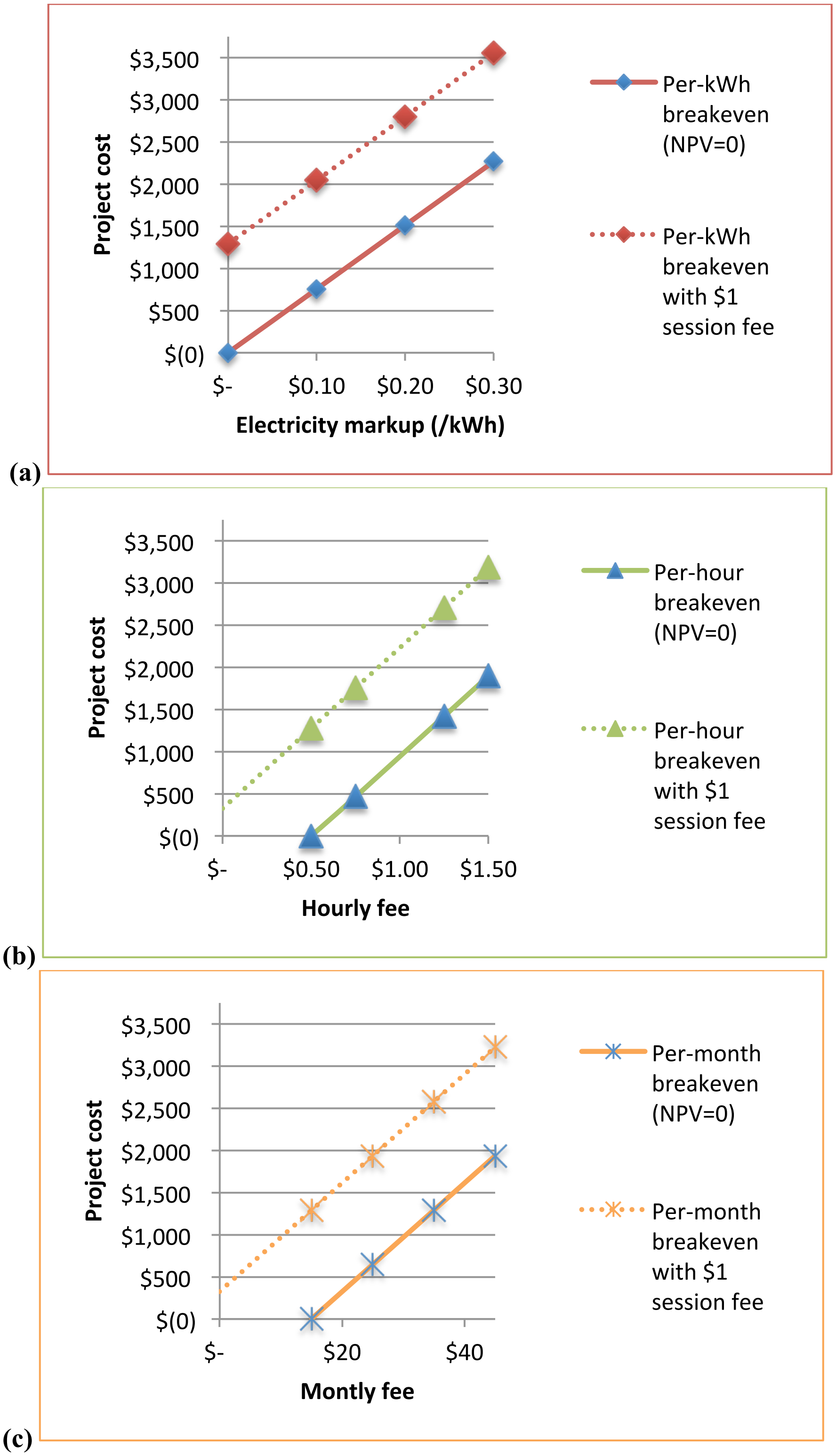

FIGURE 3-1 Workplace-Charging Investment 10-Year Net Present Value: Breakeven Pricing[a].

[a] Assumes a 5% discount rate, 240 commute days, 15-mile 1-way commute, 5.2 kWh consumed, 3.5-kW charging (L2), 1.5-hour/session, and $0.1275/kWh electricity costs in year 1. Electricity and maintenance costs and electricity markup level are escalated by 3% per year.

3.1.1 Sensitivity and Uncertainty Analysis of Financial Viability

Understanding the effects of uncertainty on financial viability is important to evaluate the robustness of net-present-value estimates. Additionally, if pricing structures respond differently to sources of uncertainty, employers may be able to minimize variability in financial returns through their choice of pricing structure. This subsection explores uncertainties and sensitivities first using the $0.30-markup/kWh price structure and level as the "base case" scenario. Following the base-case explanation, the roughly equivalent[2] $1.50/hour and $45/month fee structures are also analyzed. The results are summarized in Table 3-1.

(a) Per-kWh Case A variable fee with a $0.30/kWh markup in year 1[3] is able to recover more than $2,000 in fixed project costs with a positive NPV of $386. Of the simple (i.e., without session fee) variable-fee scenarios discussed, this is the scenario able to cover the highest fixed project costs. It is taken as the per-kWh "base case," and its more general underlying assumptions are taken as "baseline" assumptions.

To explore the importance of various inputs to this base-case estimate of $386, a Monte Carlo simulation of 50,000 trials was run on the input parameters as described in Table 3-1 using Oracle's Crystal Ball software. The "best-guess" input assumptions discussed so far are in bold and have been bounded by ranges defined by "minimum" and "maximum" estimates based on a combination of the literature sources used to produce the corresponding point estimate and author judgment. All but one range have been characterized with "triangle" probability distributions defined by linearly decreasing probability from the "best-guess" to the minimum and maximum estimates. Maintenance cost escalation, for which particularly little was known about the appropriate probability distribution, was assigned a uniform distribution across the range of values considered.

By repeatedly re-calculating the $386 NPV estimate using input values that are probabilistically picked from within the ranges described above, the Monte Carlo simulation produced a distribution of NPV estimates reflecting uncertainty in the input assumptions that can be compared to $386 point estimate. (The latter, point estimate implicitly assumes perfect knowledge about input values). In contrast to **the point-estimate of $386 for the NPV**, the Monte Carlo analysis produced a relatively symmetrical beta distribution with **a mean of $264** and a **95% confidence interval** (C.I.) ranging **from ($829) to $1,460**.

This suggests that the NPV may be somewhat lower than the point estimate indicates, but that more room exists within the 95% confidence interval for upside potential than downside potential. The last set of columns in Table 3-1 give the "contribution" produced by the specified uncertainty in each input parameter. This "contribution" is an illustrative metric produced by the Oracle software by normalizing the rank correlation coefficients between each input and the NPV estimate to illustrate how uncertainty in each input contributes to the overall distribution of NPV estimates produced over the course of the 50,000 estimations. Again, it is presented here simply to rank and roughly characterize the importance of each input and its uncertainty to the value of the NPV estimate of the base case.

The two dominant uncertainties were:

1. the distance of the one-way commute (which determines how much electricity is needed and the range for which was kept wide to acknowledge drivers are distributed across a variety of commute distances and not stacked up near the average value); and
2. maintenance costs (currently modeled as a percentage of all-in fixed costs, which in turn are the most important factor in the NPV estimation but taken as given to define each scenario).

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[2] Both in terms of cost-recovery potential, but, more particularly, to the driver—see section 3.2.

[3] i.e., ($0.1275+$0.30)/kWh in year 1, escalated by 3% per year

The electric fuel consumption of the vehicle (which also determines how much electricity is needed, but which is bounded more tightly by the range of current vehicles on the market) contributed less than 10%. Perhaps surprisingly, the uncertainty in the number of commute days per year contributes only about 1% in this analysis as structured. Parameters related to the variable cost (i.e., cost of electricity) do not contribute in this variable-rate pricing scenario, as expected.

This analysis suggests that maintenance costs need to be better understood and modeled. Additionally, if a wide range of potential commute distances need to be considered rather than a representative average, the results can be expected to vary considerably, making the decision-making process more complicated. More generally, a clearer picture is needed of facility utilization (see subsection 3.1.2).

It should also be noted that the exact method of markup may be important and should be examined further. For example, would the markup be a fixed amount or a percentage? Or would the employee be asked to pay in terms of a specific markup or a specific total price/kWh consumed? How and how often would the markup or total change over time?

Bounding Estimates Finally, to provide additional context, two non-probabilistic scenarios were also calculated to bound the base case: Simultaneously employing all of the unfavorable assumptions results in a "worst-case" NPV of ($2,135); combining the favorable assumptions results in a "best-case" NPV of $4107. It should be noted, however, that these bounding estimates are by definition unlikely; indeed, they fall well outside of the range that happened to occur during the Monte Carlo simulation, ($829) to $1,460.

(b) Per-Hour As compared to a point NPV estimate of ($148) for $1.50/hour, the Monte Carlo simulation produced a somewhat left-skewed lognormal distribution with a mean value of ($1,387) and a 95% C.I. of ($3,426) to 2,517. This indicates that $1.50/hour may be even less likely to cover $2,000 in project costs than the near-zero point estimate indicates, and that there is more room for downside than upside. Examining the contributions of the input parameters in Table 3-1, nearly three quarters is due to the possibility that higher charging power might decrease the active charging time and thus reduce billable hours. Similarly, the possibility that electricity or maintenance costs might be worse than expected also show an important potential to reduce cost recovery in this fee structure. Compared to these effects, the commute distance (or, more generally, utilization) is not very important.

(c) Per-Month As compared to the point NPV estimate of ($91) for $45/month, the Monte Carlo simulation produced a somewhat right-skewed Weibull distribution with a mean value of ($910) and a 95% C.I. of ($2,535) to $300. This indicates that $45/month may be even less likely to cover $2,000 in project costs than the near-zero point estimate indicates, and that there is much more room for downside than upside. Over half of the "contribution" is due to the possibility of higher electricity costs. Similarly, the possibility that maintenance costs might be worse than expected also shows an important potential to reduce cost recovery in this fee structure, as would higher-than expected electricity cost escalation. The assumed commute distance is relatively important, although in this case it is important to remember that decreased utilization is desirable from a cost-recovery standpoint. This creates a perverse incentive to collect monthly fees from employees but discourage PEV charging and its associated benefits.

TABLE 3-1 Uncertainty and Importance of Input Parameters: Per-kWh, Per-hour and Per-month

				+$0.30/kWh	**$1.50/hour**	**$45/month**
Point estimate				$386	($148)	($91)
Monte Carlo mean				$264	($1,387)	($910)
95% confidence interval				($829) to $1,460	($3,426) to $2,517	($2,535) to $300
Input parameter	*Min.*	***Best guess***	*Max.*	*Uncertainty Contribution*[a]		
One-way commute distance (mi) (*13*)	10	**15**	20	54%	2%	-14%
Maintenance costs (% of all-in costs) (*9, 10*)	1%	**5%**	10%	-27%	-6%	-19%
Discount rate (*19*)	3%	**5%**	10%	-8%		-1%
PEV electric fuel economy (kWh/100mi) (*14*)	30.1	**34.5**	38	6%	0.2%	2%
Escalation of markup	1%	**3%**	5%	3%		
Commute days per year	235	**240**	260	1%	0.1%	-0.3%
Maintenance cost escalation	**1%**	**Uniform (3%)**	**5%**	-1%	-0.2%	-0.3%
Charging power (kW) (*13*)	1.4	**3.5**	7.2		-73%	
Electricity cost (/kWh) (*11, 12*)	$0.0901	**$0.1275**	$0.30		-16%	-56%
Electricity cost escalation (*11*)	1%	**3%**	12%		2%	-7%

[a] Described in the text, this is a metric based on normalized rank correlation coefficients

Summary and Comparison of Uncertainty Across Fee Structures Fundamentally, commute distance is important to the per-kWh structure, as it represents sales volume. Commute distance is also important to the per-month structure, but for the opposite reason (increased charging of PEVs decreases cost-recovery). Charging power, the rate or "speed" of charging, is critically important for per-hour viability, as it determines the active charging time and thus billable hours (for reasons discussed in section 3.1). Electricity cost factors are important to both the per-hour and, in particular, per-month structures. Additionally, uncertainty in maintenance costs is important to all structures (though somewhat less so for the per-hour structure), flagging this as a priority for future refinement in the model.

Across fee structures, the effect of uncertainty in the input assumptions is to lower the NPV estimate but to provide significant room for upside potential. The per-kWh structure fares the best (smallest reduction in NPV estimate and large upside potential). The per-hour structure NPV estimate is lowered the most and has a large range (both upside and downside). The per-month upside potential is the most limited and the downside potential grows large if utilization and costs increase. The analysis of these inputs also indicates that employers wishing to minimize the variability in financial viability overall should adopt the per-kWh structure.

3.1.2 Workplace Charging Revenue Scenarios: Increasing Utilization

Under base-case assumptions, even the variable fee structure could only recover approximately $2,000 in project costs per PEV served per day, on the low side for historical installations if thinking of this as a one-Level-2-charger-per-PEV approach. This presents a challenging cost-recovery environment for many workplaces. However, several opportunities exist to improve the picture. They include possibilities mentioned above:

1. shuffling multiple employee vehicles through the EVSE-equipped parking spaces,
2. utilizing the same equipment for fleet and/or public charging when not in use by employees during off-peak times, and

3. installing low-cost, multiplexing[4] and/or low-power (e.g., Level 1) equipment.

The first option may be appropriate for certain workplaces—e.g., those with resources available for valet services or a group of motivated, early-adopter-type employees willing and available to conveniently move their cars when alerted their charging session has been completed. However, the increased resource requirements, potentially negative effects on productivity, and/or on-peak charging that might result make this option less desirable. However, it, along with the second option can be considered to improve the cost-recovery calculus in a straightforward way, for example by increasing the number of charge sessions per day or per year. The third, technological option may be the most widely desirable as it has the potential to increase utilization while simultaneously lowering certain project costs or barriers (e.g., electric panel capacity, equipment power ratings, etc.).

Regardless of the means by which utilization is increased, if equipment use increases significantly, the argument grows for either assessing at least part of the maintenance and operation costs on a variable basis per kWh consumed and/or explicitly accounting for accelerated equipment replacement, effects reserved for future work.

Table 3-2 illustrates the effect of increasing Level 2 equipment utilization on the NPV of the base case. It does so using two metrics: the average number of kWh charged per commute day and the average number of electric miles provided per commute day.

As seen for the $0.30/kWh-markup case in Table 3-2a, doubling the utilization of the charger to 10.4 kWh per day (equivalent to 30 e-miles) yields enough revenue to support $4,000 of investment. If the charger could be used more intensively without undue valet, worker-productivity, or peak-electricity costs, the tripling or quadrupling of utilization supports over $6,000 and $9,000 of financially viable investment, respectively.

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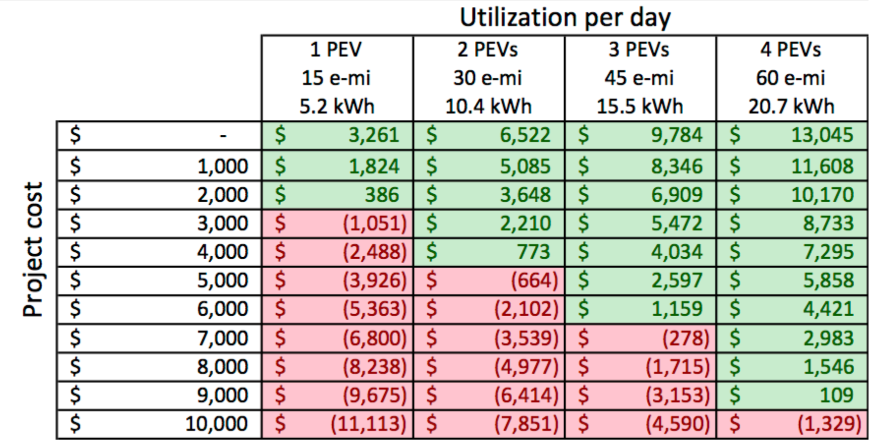
[4] i.e., equipment that can charge multiple vehicles using one circuit and/or off-board charger, e.g., through use of multiple cords and control of the amount or timing of power sent to each vehicle

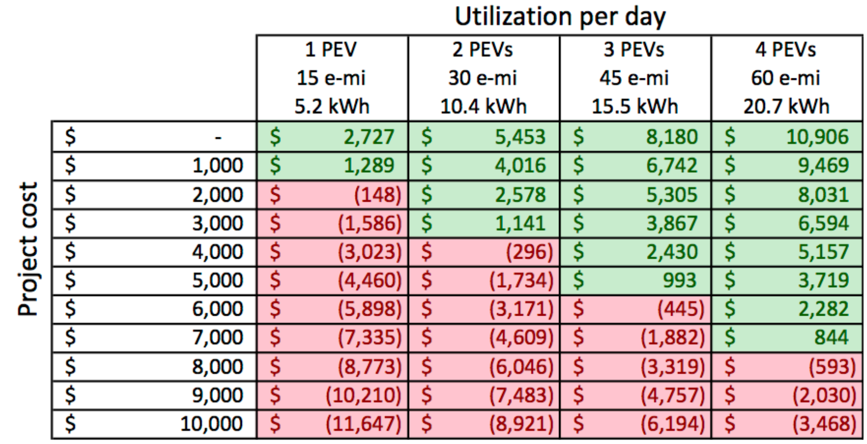
TABLE 3-2 Utilization Scenarios

a) **$0.30/kWh markup**



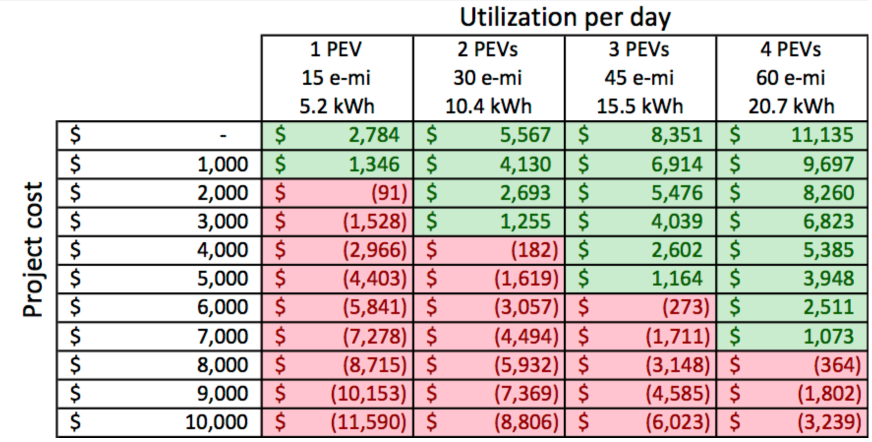
Project cost	1 PEV 15 e-mi 5.2 kWh	2 PEVs 30 e-mi 10.4 kWh	3 PEVs 45 e-mi 15.5 kWh	4 PEVs 60 e-mi 20.7 kWh
	Utilization per day			
$ -	$ 3,261	$ 6,522	$ 9,784	$ 13,045
$ 1,000	$ 1,824	$ 5,085	$ 8,346	$ 11,608
$ 2,000	$ 386	$ 3,648	$ 6,909	$ 10,170
$ 3,000	$ (1,051)	$ 2,210	$ 5,472	$ 8,733
$ 4,000	$ (2,488)	$ 773	$ 4,034	$ 7,295
$ 5,000	$ (3,926)	$ (664)	$ 2,597	$ 5,858
$ 6,000	$ (5,363)	$ (2,102)	$ 1,159	$ 4,421
$ 7,000	$ (6,800)	$ (3,539)	$ (278)	$ 2,983
$ 8,000	$ (8,238)	$ (4,977)	$ (1,715)	$ 1,546
$ 9,000	$ (9,675)	$ (6,414)	$ (3,153)	$ 109
$ 10,000	$ (11,113)	$ (7,851)	$ (4,590)	$ (1,329)

b) **$1.50/hour**



Project cost	1 PEV 15 e-mi 5.2 kWh	2 PEVs 30 e-mi 10.4 kWh	3 PEVs 45 e-mi 15.5 kWh	4 PEVs 60 e-mi 20.7 kWh
	Utilization per day			
$ -	$ 2,727	$ 5,453	$ 8,180	$ 10,906
$ 1,000	$ 1,289	$ 4,016	$ 6,742	$ 9,469
$ 2,000	$ (148)	$ 2,578	$ 5,305	$ 8,031
$ 3,000	$ (1,586)	$ 1,141	$ 3,867	$ 6,594
$ 4,000	$ (3,023)	$ (296)	$ 2,430	$ 5,157
$ 5,000	$ (4,460)	$ (1,734)	$ 993	$ 3,719
$ 6,000	$ (5,898)	$ (3,171)	$ (445)	$ 2,282
$ 7,000	$ (7,335)	$ (4,609)	$ (1,882)	$ 844
$ 8,000	$ (8,773)	$ (6,046)	$ (3,319)	$ (593)
$ 9,000	$ (10,210)	$ (7,483)	$ (4,757)	$ (2,030)
$ 10,000	$ (11,647)	$ (8,921)	$ (6,194)	$ (3,468)

c) **$45/month**



Project cost	1 PEV 15 e-mi 5.2 kWh	2 PEVs 30 e-mi 10.4 kWh	3 PEVs 45 e-mi 15.5 kWh	4 PEVs 60 e-mi 20.7 kWh
	Utilization per day			
$ -	$ 2,784	$ 5,567	$ 8,351	$ 11,135
$ 1,000	$ 1,346	$ 4,130	$ 6,914	$ 9,697
$ 2,000	$ (91)	$ 2,693	$ 5,476	$ 8,260
$ 3,000	$ (1,528)	$ 1,255	$ 4,039	$ 6,823
$ 4,000	$ (2,966)	$ (182)	$ 2,602	$ 5,385
$ 5,000	$ (4,403)	$ (1,619)	$ 1,164	$ 3,948
$ 6,000	$ (5,841)	$ (3,057)	$ (273)	$ 2,511
$ 7,000	$ (7,278)	$ (4,494)	$ (1,711)	$ 1,073
$ 8,000	$ (8,715)	$ (5,932)	$ (3,148)	$ (364)
$ 9,000	$ (10,153)	$ (7,369)	$ (4,585)	$ (1,802)
$ 10,000	$ (11,590)	$ (8,806)	$ (6,023)	$ (3,239)

3.2 Fueling-Cost Benchmarks: Workplace Charging and Gasoline Equivalents

This subsection provides benchmarks to facilitate the comparison of the driver costs of various fueling alternatives. For each of the three price structures—per-kWh, per-hour, and per-month—and four price levels—e.g., 1=$0.50/hour, 2=$0.75/hour, 3=$1.25/hour, and 4=$1.50/hour—Table 3-3 translates the fueling costs into the dollars-per-electric-mile equivalent for the workplace-charging base case (column 2). It also shows equivalents for electricity (per-kWh, column 3) and gasoline (per-gallon, columns 4 and 5), representing the fueling alternatives facing a PEV driver (i.e., residential charging and gasoline refueling). Gasoline equivalents are shown both relative to a conventional vehicle (CV) baseline of 27.2 mpg and a sales-weighted plug-in-hybrid electric vehicle (PHEV) baseline of 41 mpg.

Note that each price level is roughly equivalent on a dollars-per-electric-mile basis: level 1=5¢, level 2=8¢, level 3=12¢, and level 4=15¢ per electric mile.

Compared to a conventional vehicle, the "breakeven" $0.00/kWh-markup scenario in Table 3-3 illustrates that covering only the marginal cost of average workplace electricity presents the employee driver with a low gasoline-equivalent price ($1.20/gal), and thus a large incentive to drive a PEV to work and charge. Even covering markups of up to roughly $0.20/kWh ("medium price") provides financial motivation, and a $0.30/kWh markup ("high price") provides rough cost parity with California gasoline. Recall that the $0.30/kWh markup was assumed as the base case as necessary for the employer to cover roughly $2,000 of total project costs. Acknowledging that the driver may consider some additional private or social value (e.g., from the convenience of workplace charging, parking or other associated benefits, increased zero-emission/oil-free travel, etc.), this nevertheless might represent a reasonable maximum markup that the employer could expect employees to fully utilize in the near term.

Similar scenarios for each of the hourly and monthly price structures indicate that, compared to a conventional vehicle, an economic incentive exists for PEV drivers to use workplace charging at prices at or below roughly $1.25/hour or $35/month, respectively (scenario group #3, "medium prices").

TABLE 3-3 Alternative Fueling Cost Benchmarks: Workplace Charging Baseline and Gasoline

Pricing Level	$ per electric mile	Electricity equivalent	Gasoline equiv. (CV)	Gasoline equivalent (PHEV or hybrid)
1. breakeven prices			*"A Steal"*	*"Incentivizing"*
Electricity cost=$0.1275/kWh (in year 1)	$0.04/e-mi	*$0.13/kWh*	$1.20/gal	$1.80
$0.50/hour actively charging	$0.05/e-mi	$0.14/kWh	$1.34/gal	$2.02
$15/month	$0.05/e-mi	$0.14/kWh	$1.36/gal	$2.05
2. low prices			*"Incentivizing"*	*"Cheap"*
$0.75/hour actively charging	$0.07/e-mi	$0.21/kWh	$2.01/gal	$3.03
Electricity cost + $0.10/kWh	$0.08/e-mi	*$0.23/kWh*	$2.14/gal	$3.22
$25/month	$0.08/e-mi	$0.24/kWh	$2.27/gal	$3.42
3. medium prices			*"Cheap"*	*"Uncompetitive"*
Electricity cost + $0.20/kWh	$0.11/e-mi	*$0.33/kWh*	$3.08/gal	$4.64
$35/month	$0.12/e-mi	$0.34/kWh	$3.17/gal	$4.78
$1.25/hour actively charging	$0.12/e-mi	$0.36/kWh	$3.35/gal	$5.05
Low gasoline price	$0.13/e-mi	$0.37/kWh	*$3.50/gal*	
Gasoline price (~CA 2012 average)	$0.15/e-mi	$0.43/kWh	*$4.00/gal*[a]	
4. high prices			*"Equivalent"*	*"Forget about it"*
Electricity cost + $0.30/kWh	$0.15/e-mi	*$0.43/kWh*	$4.01/gal	$6.05
$1.50/hour actively charging	$0.15/e-mi	$0.43/kWh	$4.02/gal	$6.07
$45/month	$0.15/e-mi	$0.43/kWh	$4.08/gal	$6.13
High gasoline price	$0.16/e-mi	$0.48/kWh	*$4.50/gal*	

[a] http://articles.latimes.com/2013/jan/01/business/la-fi-gas-prices-20130101

CV=conventional vehicle, PHEV=plug-in-hybrid electric vehicle

An interesting picture develops in column 5 for the plug-in-hybrid driver, however, who has the option to forego recharging and use gasoline at any time. Because hybrids, including plug-in hybrids, are more efficient at utilizing gasoline, the costs of workplace charging appear relatively less favorable to these drivers. Using the sales-weighted, EPA-rating average of roughly 41 mi/gal, these drivers see each pricing group (1, 2, 3, or 4) as at least one group less attractive than it appears to the conventional-vehicle driver.

For example, the "cheap gasoline" group (#3) of $1.25/hour, $35/month, and $0.20-markup scenarios looks uncompetitive to the driver of a vehicle that efficiently uses gasoline.

The comparison is even worse for drivers that have a better-than-average vehicle at their disposal. For example, a driver of a plug-in Prius (50 mi/gal when on gasoline) would have a larger incentive not to use expensively-priced workplace charging than a Volt driver, who in turn might view scenario-group-3 price levels skeptically.

It should further be noted that several all-gasoline hybrids without plug-in capability (e.g., from Toyota and Ford) achieve better gasoline efficiency than the plug-in-hybrid sales-weighted average of 41 mi/gal. To name the most popular example, the "regular" MY2012 Prius also has an EPA-rated fuel economy of 50 mi/gal. Thus, even an all-battery EV driver that cannot switch to gasoline on the fly might choose to leave the PEV at home and drive their regular gasoline-only Prius to work if workplace-charging prices are at scenario-group-3 levels.

3.2.1 Sensitivity and Uncertainty Analysis of Driver Cost Calculations

Following section 3.1.1, sensitivity analysis was conducted on the inputs to the "electricity cost + $0.20/kWh" driver-fueling-cost calculation. The additional key input is conventional vehicle fuel economy, which was allowed to range from 22.8 mi/gal (described above) to 29 mi/gal (based on three years of historical change to allow for any increases that have started to occur after 2011 as consumer preferences change and new vehicle standards begin to take effect).

The Monte Carlo and bounding analyses indicate the point estimates are reasonable, though the range produced extends to much higher (less competitive) gasoline-equivalent prices. Uncertainty in the costs of electricity contributes nearly four fifths of the uncertainty in the fuel cost estimate, whereas assumed vehicle efficiencies contributed only about a tenth each.

This analysis suggests that the benchmarks presented above are reasonable so long as electricity costs are near the average value of $0.1275. As electricity costs increase toward $0.30/kWh, the financial incentive to even the driver with an inefficient conventional vehicle vanishes.

Bounding Estimates Simultaneously employing all of the unfavorable assumptions results in a "worst-case" fueling cost of $4.36/gal equivalent; combining the favorable assumptions results in a "best-case" fueling cost of $2.51/gal equivalent. These estimates happen to align well with the 95% confidence range of the simulation.

4 CONCLUSIONS

This analysis finds limited opportunity for employer cost recovery at prices that employee drivers might find financially motivating. Prices on the order of $0.33/kWh (including electricity costs and markup), $1.25/hour-of-active-charging, or $35/month allow recovery of only $1,000–$2,000 in station investment per vehicle served under the baseline assumptions examined herein. However these price levels may be considered uncompetitive to a sales-weighted average plug-in-hybrid driver. Plug-in-hybrid EV drivers with better-than-average vehicles—or even all-battery EV drivers with an efficient all-gasoline hybrid as a second vehicle—might be even less tolerant. Compared to a 50-mi/gal alternative, workplace-charging prices might have to be kept below $0.23/kWh, $0.80/hour of active charging, or $24/month.

For a given level of cost recovery, each pricing structure has unique characteristics. Per-kWh pricing benefits from the sales volume brought about by greater commute distances or other increases in utilization, per-hour pricing is negatively affected by higher charging power, and per-month profitability is subject to electricity-cost risk. Analysis of financial viability calculations indicates the per-kWh pricing structure offers significant upside potential while being less negatively affected by uncertainty in the inputs, both on average and in terms of minimizing variability in expected cost recovery.

Further differences are indicated here and could be explored in future work. The hourly rate structure has the disadvantage of potentially discriminating against older PEV models that charge more slowly and thus will effectively pay more per fill than will new PEVs. If not based only on the time spent actively charging, it may also discriminate against vehicles that do not require a lot of charge. For example, it may only take roughly 1.5 hours to recharge the 15-mile commute, even for older PEVs. Unless drivers move their cars or are not billed for the time after charging is completed, their costs per kilowatt-hour continue to rise, quickly reaching uncompetitive levels.

Both the hourly and markup fee structures come with the added costs to employers of measuring and billing for the quantity of electricity or time that PEVs consume. As a flat-rate structure, the per-month method avoids these measurement and billing costs for employers but has the disadvantages of both creating the perverse incentive to minimize charging and imposing different unit costs (e.g., cost per electric mile driven) on PEV drivers who travel differing numbers of e-miles daily.

Regardless of pricing structure, increasing facility utilization could significantly improve potential profitability. However, this might prove challenging for workplaces wishing to avoid potential costs due to afternoon on-peak charging and/or the need to shuffle cars. Low-cost solutions that increase utilization while minimizing per-vehicle installation and management costs (e.g., multiplexed, perhaps lower-power charging facilities) might help address these constraints, and should be a part of ongoing analysis to better understand the costs and benefits of implementing PEV recharging at the workplace.

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