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Pricing Plug-in Electric Vehicle Recharging in Multi-Unit Dwellings:

Financial Viability and Fueling Costs

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ABSTRACT

This research explores whether pricing structures and levels likely to provide multi-unit-dwelling drivers with financial motivation to recharge at home might provide sufficient opportunity for station cost recovery. Compared to a popular 50 mile-per-gallon gasoline hybrid baseline, residential charging prices might have to be kept below \$0.26/kWh, \$1.00/hour of active charging, or \$85/month—levels that only support roughly \$1,000–2,000 in facility investment per vehicle served. Increasing facility utilization while minimizing per-vehicle costs is key to improving financial viability and, across pricing structures, could more than double the cost recovery potential. Further, site hosts' choice of pricing structure will differentially affect their ability to remain financially viable in the face of input-parameter uncertainty.

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1. Introduction

1.1 Background, Objectives, and Article Structure

Overnight recharging at home is expected to be the most prevalent and cost-effective way to refuel plug-in electric vehicles (PEVs) [1]. This is due to factors such as long and regular vehicle residence times [2]. Nevertheless, the implementation of residential recharging remains particularly challenging in multi-unit dwelling (MUD) environments as stakeholders wrestle with this relatively new phenomenon and its potential costs and benefits in a wide variety of contexts. Site hosts (e.g. landlords or property owners), 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 MUDs.

This research assesses recharging at MUDs from two main perspectives: i) site hosts investing in MUD recharging facilities and pricing their use and ii) resident PEV 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) exploring the opportunity for facility cost recovery at prices that resident 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 driving and vehicle characteristics,
4) describing how choice of pricing strategy affects facility viability 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

The following describes the framework and assumptions used to analyze 1) MUD recharging facility financial viability (subsection 2.1), and 2) fueling costs for PEV drivers in MUDs (subsection 2.2)

2.1 MUD Recharging Facility Financial Model Elements

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

2.1.1 Costs

Recharging-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.

Fixed Costs (Upfront and Periodic) Because of the wide variety of facility cost structures (reserved for future work) and in order to allow flexible exploration of a variety of cost levels, the financial modeling employed herein does not attempt to model MUD recharging facility costs. Rather, it explicitly presents a range of "all-in" fixed investment levels (one per row in Table 3-1and Table 3-3). This allows the reader to choose different levels (i.e., pick different rows) appropriate to different situations, as described in subsection 3.1.

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, customer 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 $0.1640/kWh, the average price of residential electricity in California[1] in the most recent quarter (2Q2013) [7].

For the purposes of uncertainty analysis, it is assumed variable costs range from a U.S. low of $0.0867/kWh (2Q2013 Washington) to a high of $0.3704/kWh (2Q2013 Hawai'i) [7].

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.

2.1.3 Facility Utilization Assumptions

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 [8]. The amount of energy required is dependent on the state of charge of the vehicle when it plugs in, which depends largely on the daily driving distance, assumed here to average 30 miles per day [8].

In order to calculate how many kWh will be needed to recharge PEVs that have traveled, on average, that daily commute distance (30 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 34.1 kWh/100 miles. This is an average of the U.S. Environmental Protection Agency's adjusted electric economy ratings for PEVs weighted by aggregated sales data through August 2013 [9].

Thus, to recover from a 30-mile day, the charging facility needs to provide 0.341 kWh/mi or 10.2

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[1] This assumption does not fully take into account the possibility that energy purchased to charge PEVs could move the building 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 location'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.

kWh per vehicle. At the 3.5-kW Level 2 charging rate, this would take approximately 2.9 hours. It is further assumed that the charging equipment will be utilized 7 days per week for 50 weeks out of the year, or 350 days per year.

2.2 Fueling Costs Calculations for Resident Drivers: Additional Inputs

This subsection describes additional assumptions used in calculating the costs of recharging at home for MUD residents facing the variety of pricing structures and levels described above. Key additional inputs used include 1) the sales-weighted, EPA-rating plug-in-hybrid average gasoline fuel economy of approximately 41.1 miles per gallon (mi/gal) and 2) conventional-vehicle fuel economy of 27.2 mi/gal. The former was calculated based on PEV sales [9] 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 [10]. 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 MUD Recharging Facility Financial Viability and Pricing Options

This subsection presents an analysis of recharging station profitability as a function of various pricing structures and levels (3.1.1) and examines both uncertainty in input parameters (3.1.2) and increasing station utilization (3.1.3).

3.1.1 Residential Recharging Facility Financial Viability

Table 3-1 illustrates the effect that various inputs, including nine "all-in" investment cost levels (one per row), have on the present value of recharging facility net revenues. In situations where the net present value is positive, costs are recovered and the facility investment is potentially profitable. The table allows exploration of individual situations seen by MUDs at specific locations with varying conditions. Additionally, it allows exploration of the effect of incentives that change cost levels, reserved for future work.

Table 3-1 has six parts (a–f) presenting the 10-year present value of net revenues[2] resulting from three basic price structures: per-kWh (a, b), per-hour (c, d), and per-month (e, f). Per-kWh and per-hour structures are presented both with (b, d) and without (a, c) an additional fixed fee per charging session. The per-month structure is presented both with an additional fee to cover electricity costs (f) and without the additional fee (e).

Each column of the table is for a different fee (price) level. Per-kWh scenarios include columns based on the amount of the markup added to the electricity costs passed on to the driver. Per-hour and per-month scenarios include columns based on the level of those fees. The first fee-level column in parts a, c, and e presents the approximate 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. $0.65/hour and $55/month are rough equivalents, given electricity costing $0.1640/kWh, 30 miles, and 350-day-per-year use. The next three columns 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,

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[2] It should be noted that the only revenues represented in Table 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 [11, 12]). Eventually, recharging 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.

the third column might still provide the driver with some advantage over fueling on gasoline at today's prices, whereas the fourth column might be considered uncompetitive with gasoline, on the whole. The exception are the fees in part f: to achieve similar cost-recovery potential, higher fees (per-month + electricity charges) are required and will be less active to driver than the equivalent fees shown in parts b and d.

In general, it appears possible to recover roughly five thousand dollars of investment on one charging unit. This is not unlike the initial situation facing many locations that:

1) want to test the waters by providing one charging point, or whose cost structure makes it difficult to provide the first few parking spots with EVSE at costs much less than a couple thousand dollars per unit;
2) wish to limit charging in the afternoon and evening to avoid peaks in either energy charges or facility demand charges (if applicable);
3) do not wish to create a potentially complex, costly, and/or driver-time-consuming system involving moving of cars in and out of charging locations to increase the number of charge events per day; and/or
4) do not have synergistic opportunities to open their recharging facilities to public vehicles when resident charging is unneeded.

Nevertheless, it is clear that, for those locations concerned with profitable operation of their recharging facilities, increasing utilization and/or reducing average unit costs are important. These topics are explored in subsection 3.1.2 and future work.

Sub-tables b and d show the effect of adding an additional $1 fixed fee per session (for per-kWh and per-hour structures). This increases the cost-recovery potential of a given simple fee structure from up to $5,000–6,000 to up to $7,000–8,000 in investment. The effect is similar for the per-month structure (not shown), and somewhat smaller than charging an additional fee to cover electricity costs in the per-month structure, which equates in this driving scenario to a $1.68 fixed fee (sub-table f). In a similar vein, the site host might be tempted to confound parking and recharging pricing in such a way that the PEV driver continues to get charged for occupying a recharging space after active recharging is completed. For a given amount of time after charging, these parking fees act as additional fixed (relative to the amount or duration of charging) fees.

However, for reasons discussed here and elsewhere [13], 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 recharging to several dollars, not several cents, per kilowatt-hour received. This might be counterproductive to adoption of MUD charging by the majority of the PEV market that drives plug-in-hybrids or neighborhood electric vehicles (NEVs).

Table 3-1. MUD Recharging Investment 10-Year Net Present Value[a]

a) **Fee structure** per-kWh **Session fee** $0.00

		Electricity markup			
		$ -	$ 0.10	$ 0.20	$0.30
Project Cost	$ -	$ (0)	$ 2,763	$ 5,526	$ 8,289
	$ 1,000	$ (1,437)	$ 1,326	$ 4,089	$ 6,852
	$ 2,000	$ (2,875)	$ (112)	$ 2,652	$ 5,415
	$ 3,000	$ (4,312)	$ (1,549)	$ 1,214	$ 3,977
	$ 4,000	$ (5,750)	$ (2,986)	$ (223)	$ 2,540
	$ 5,000	$ (7,187)	$ (4,424)	$ (1,661)	$ 1,103
	$ 6,000	$ (8,624)	$ (5,861)	$ (3,098)	$ (335)
	$ 7,000	$ (10,062)	$ (7,299)	$ (4,535)	$ (1,772)
	$ 8,000	$ (11,499)	$ (8,736)	$ (5,973)	$ (3,210)

b) **Fee structure** per-hour **Session fee** $0.00

		Hourly fee			
		$ 0.65	$ 1.00	$ 1.35	$ 1.70
Project cost	$ -	$ (2)	$ 2,761	$ 5,524	$ 8,287
	$ 1,000	$ (1,439)	$ 1,324	$ 4,087	$ 6,850
	$ 2,000	$ (2,877)	$ (114)	$ 2,649	$ 5,413
	$ 3,000	$ (4,314)	$ (1,551)	$ 1,212	$ 3,975
	$ 4,000	$ (5,752)	$ (2,988)	$ (225)	$ 2,538
	$ 5,000	$ (7,189)	$ (4,426)	$ (1,663)	$ 1,101
	$ 6,000	$ (8,626)	$ (5,863)	$ (3,100)	$ (337)
	$ 7,000	$ (10,064)	$ (7,301)	$ (4,537)	$ (1,774)
	$ 8,000	$ (11,501)	$ (8,738)	$ (5,975)	$ (3,212)

c) **Fee structure** per-month **Electricity fee** $0.00

		Monthly fee			
		$ 55	$ 85	$ 115	$ 145
Project cost	$ -	$ (37)	$ 2,743	$ 5,522	$ 8,302
	$ 1,000	$ (1,475)	$ 1,305	$ 4,085	$ 6,865
	$ 2,000	$ (2,912)	$ (132)	$ 2,648	$ 5,427
	$ 3,000	$ (4,349)	$ (1,570)	$ 1,210	$ 3,990
	$ 4,000	$ (5,787)	$ (3,007)	$ (227)	$ 2,553
	$ 5,000	$ (7,224)	$ (4,444)	$ (1,664)	$ 1,115
	$ 6,000	$ (8,662)	$ (5,882)	$ (3,102)	$ (322)
	$ 7,000	$ (10,099)	$ (7,319)	$ (4,539)	$ (1,759)
	$ 8,000	$ (11,536)	$ (8,756)	$ (5,977)	$ (3,197)

d) **Fee structure** per-kWh **Session fee** $1.00

		Electricity markup			
		$ -	$ 0.10	$ 0.20	$ 0.30
Project Cost	$ -	$ 2,703	$ 5,466	$ 8,229	$ 10,992
	$ 1,000	$ 1,265	$ 4,028	$ 6,792	$ 9,555
	$ 2,000	$ (172)	$ 2,591	$ 5,354	$ 8,117
	$ 3,000	$ (1,610)	$ 1,154	$ 3,917	$ 6,680
	$ 4,000	$ (3,047)	$ (284)	$ 2,479	$ 5,243
	$ 5,000	$ (4,484)	$ (1,721)	$ 1,042	$ 3,805
	$ 6,000	$ (5,922)	$ (3,159)	$ (395)	$ 2,368
	$ 7,000	$ (7,359)	$ (4,596)	$ (1,833)	$ 930
	$ 8,000	$ (8,796)	$ (6,033)	$ (3,270)	$ (507)

e) **Fee structure** per-hour **Session fee** $1.00

		Hourly fee			
		$ 0.65	$ 1.00	$ 1.35	$ 1.70
Project cost	$ -	$ 2,701	$ 5,464	$ 8,227	$ 10,990
	$ 1,000	$ 1,263	$ 4,026	$ 6,789	$ 9,553
	$ 2,000	$ (174)	$ 2,589	$ 5,352	$ 8,115
	$ 3,000	$ (1,612)	$ 1,152	$ 3,915	$ 6,678
	$ 4,000	$ (3,049)	$ (286)	$ 2,477	$ 5,240
	$ 5,000	$ (4,486)	$ (1,723)	$ 1,040	$ 3,803
	$ 6,000	$ (5,924)	$ (3,161)	$ (397)	$ 2,366
	$ 7,000	$ (7,361)	$ (4,598)	$ (1,835)	$ 928
	$ 8,000	$ (8,798)	$ (6,035)	$ (3,272)	$ (509)

f) **Fee structure** per-month **Electricity fee** $0.1640 (year 1)

		Monthly fee			
		$ 55	$ 85	$ 115	$ 145
Project cost	$ -	$ 5,096	$ 7,876	$ 10,656	$ 13,436
	$ 1,000	$ 3,659	$ 6,439	$ 9,219	$ 11,998
	$ 2,000	$ 2,222	$ 5,001	$ 7,781	$ 10,561
	$ 3,000	$ 784	$ 3,564	$ 6,344	$ 9,124
	$ 4,000	$ (653)	$ 2,127	$ 4,906	$ 7,686
	$ 5,000	$ (2,091)	$ 689	$ 3,469	$ 6,249
	$ 6,000	$ (3,528)	$ (748)	$ 2,032	$ 4,812
	$ 7,000	$ (4,965)	$ (2,185)	$ 594	$ 3,374
	$ 8,000	$ (6,403)	$ (3,623)	$ (843)	$ 1,937

[a] Assumes a 5% discount rate, 350 commute days, 30 miles of daily driving, 10.2 kWh consumed, 3.5-kW charging (L2), 2.9-hour/session, and $0.1640/kWh electricity costs in year. Electricity and maintenance costs are escalated by 3% per year.

3.1.2 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 (e.g., in the daily driving distance of residents, maintenance and electricity costs, etc.), site hosts 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[3] $1.70/hour and $145/month fee structures are also analyzed. The results are summarized in Table 3-2.

(a) Per-kWh Case The net-present value (NPV) of the scenario in the third cost row and last markup column in Table 3-1a is estimated to be approximately $1,103. This indicates that a variable fee with a $0.30/kWh markup[4] is able to recover $5,000 in fixed project costs. 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 $1,103, a Monte Carlo simulation of 50,000 trials was run on the input parameters as described in Table 3-2 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 it was thought 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 $1,103 net-present value 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 $1,103 point estimate. (The latter, point estimate implicitly assumes perfect knowledge about input values).

In contrast to **the point-estimate of $1,103 for the NPV**, the Monte Carlo analysis produced a relatively symmetrical beta distribution with **a mean of $946** and a **95% confidence interval** (C.I.) ranging **from ($2,879) to $5,493**.

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 column in Table 3-2 gives the "contribution" produced by the specified

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

[4] i.e., ($0.1640+$0.30)/kWh in year 1, where the electricity cost is escalated by 3% per year

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 daily driving distance (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 for each row of Table 3-1). Table 3-1The 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 just less than 10%. The uncertainty in the number of drive days per year contributes about 7% in this analysis as structured, and the discount rate and escalations contributed 4% or less each. 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 drive 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 resident driver 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?

(b) Per-Hour As compared to the point NPV estimate of $1,101 for $1.70/hour from , the Monte Carlo simulation produced a somewhat left-skewed max. extreme distribution with a mean value of ($1,980) and a 95% confidence interval of ($9,478) to $9,576. This indicates that $1.70/hour may be much less likely to cover $5,000 in project costs than the point estimate indicates, and that there is considerable room for both downside and upside (though the median and mode are both more negative than the mean). Examining the contributions of the input parameters in Table 3-2, nearly seventy percent is due to the possibility that higher charging power might decrease the active charging time and thus reduce billable hours. Uncertainty in electricity costs contributes another 20%. Uncertainty in the daily driving distance contributes roughly 4%. Similar in size but opposite in direction, the possibility that maintenance costs or increases in electricity prices might be worse than expected also show a modest potential to reduce cost recovery in this fee structure. Overall, utilization is not very important.

(c) Per-Month As compared to the point NPV estimate of $1,115 for $145/month from Table 3-1, the Monte Carlo simulation produced a somewhat right-skewed Weibull distribution with a mean value of ($977) and a 95% confidence interval of ($7,216) to $3,371. This indicates that $145/month may be less likely to cover $5,000 in project costs than the 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. The assumed daily driving distance contributes over a quarter, making it relatively important to this price structure. In this case, however, 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 resident drivers but discourage PEV charging and its associated benefits. Contributing less than ten percent are the possibility that maintenance costs might be worse than expected, higher-than expected electricity cost escalation, poorer than expected vehicle economy, and fewer drive days per year than expected.

Table 3-2. Uncertainty and Importance of Input Parameters: Per-kWh, Per-hour and Per-month

				+$0.30/kWh	$1.70/hour	$145/mo.
			Point estimate	$1,103	($1,101)	($91)
			Monte Carlo mean	$946	($2,056)	($977)
			95% confidence interval	($2,879) to $5,493	($9,478) to $9577	($7,216) to $3,371
Input parameter	*Min.*	***Best guess***	*Max.*	*Uncertainty Contribution*[a]		
Daily driving distance (mi)	15	**30**	45	64%	4%	-25%
Maint. costs (% of all-in costs)	1%	**5%**	10%	-13%	-3%	-9%
PEV electric fuel economy (kWh/100mi)	28.6	**34.1**	43.2	10%	1%	-4%
Drive days per year	260	**350**	365	7%	0.5%	-3%
Discount rate	3%	**5%**	10%	-4%		-1%
Escalation of markup	1%	**3%**	5%	3%		
Maintenance cost escalation	**1%**	**Uniform (3%)**	**5%**	-0.3%	-0.1%	-0.2%
Charging power (kW)	1.4	**3.5**	7.2		-68%	
Electricity cost (/kWh)	$0.0867	**$0.1640**	$0.3704		-20%	-52%
Electricity cost escalation	1%	**3%**	12%		3%	-6%

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

Summary and Comparison of Uncertainty Across Fee Structures Fundamentally, driving distance is important to the per-kWh structure, as it represents sales volume. Driving 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 site hosts wishing to minimize the variability in financial viability overall should adopt the per-kWh structure.

3.1.3 Revenue Scenarios: Increasing Utilization to Improve Cost Recovery

Thus far, the financial analysis has focused on the initial installation and use of one Level 2 charger by one PEV once per day, perhaps reasonable for MUDs with assigned parking. Under these conditions, and the various other assumptions described for the base case above, even the variable fee structure could only recover approximately $5,000 in project costs. Depending on the MUD environment (e.g., location of electrical panel relative to the parking, amount of required trenching), this may or may not be adequate for facility construction and installation. However, several opportunities exist to improve the picture. They include:

1) shuffling multiple resident vehicles through the EVSE-equipped parking spaces,
2) utilizing the same equipment for fleet and/or public charging when not in use by residents, ideally during off-peak times, and
3) installing low-cost, multiplexing[5] and/or low-power (e.g., Level 1) equipment.

The first two options may not be appropriate for certain MUDs. However, if available, they 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 3-3 illustrates the effect of increasing Level 2 equipment utilization on the NPV of the base case. It does so using three metrics: the average number of kWh charged per day, the average number of electric miles provided per day, and the number of PEVs served. The first two

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[5] 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

are directly related to one another, and the third (number of PEVs served) becomes important for the per-month price structure (highlighted below). It also explicitly examines one *decreased* utilization scenario (treated implicitly above as the lower bound in the uncertainty analysis), that where the vehicle returns home with only 15 miles of charge to recover (e.g., a shorter-than-average driving day, or one involving additional, non-residential charging).

As seen for the $0.30/kWh-markup case in Table 3-3a, doubling the utilization of the charger to 20.4 kWh per day (equivalent to 60 e-miles) yields enough revenue to support over $10,000 of investment. If the charger could be used in this way without undue valet, peak-electricity, and/or resident-inconvenience costs, it is likely to recover the investment required at a wide variety of MUDs. A very similar picture is seen for the roughly comparable $1.70/hour price structure and level.

The per-month fee structure presents a more complex picture. Increasing facility utilization by a given number of customers *decreases* cost recovery potential as increasing electricity costs eat away at fixed subscription-fee revenues. This is seen when comparing the first and second columns in Table 3-3c, for 1 PEV, and when comparing the third and fourth columns, for 2 PEVs. However, comparing the second and third columns illustrates the effect of increasing the number of per-month subscribers from 1 to 2, thereby doubling revenues from $145 to $290 per month. Where multiple per-month subscribers might be able to use a single charger, the cost-recovery picture improves dramatically. As indicated above, this could be achieved (at varying costs) through either temporal shuffling of cars in and out of the parking space or via multiplex shuffling of electrons flowing from the charger through multiple cords to multiple cars.

Table 3-3. Utilization Scenarios

a) **$0.30/kWh markup**

		Utilization per day			
		0.5 PEVs	1 PEV	1.5 PEVs	2 PEVs
		15 e-mi	30 e-mi	45 e-mi	60 e-mi
		5.1 kWh	10.2 kWh	15.3 kWh	20.4 kWh
Project cost	$ -	$ 4,145	$ 8,289	$ 12,434	$ 16,579
	$ 1,000	$ 2,707	$ 6,852	$ 10,997	$ 15,141
	$ 2,000	$ 1,270	$ 5,415	$ 9,559	$ 13,704
	$ 3,000	$ (167)	$ 3,977	$ 8,122	$ 12,267
	$ 4,000	$ (1,605)	$ 2,540	$ 6,685	$ 10,829
	$ 5,000	$ (3,042)	$ 1,103	$ 5,247	$ 9,392
	$ 6,000	$ (4,480)	$ (335)	$ 3,810	$ 7,955
	$ 7,000	$ (5,917)	$ (1,772)	$ 2,372	$ 6,517
	$ 8,000	$ (7,354)	$ (3,210)	$ 935	$ 5,080
	$ 9,000	$ (8,792)	$ (4,647)	$ (502)	$ 3,642
	$ 10,000	$ (10,229)	$ (6,084)	$ (1,940)	$ 2,205

b) **$1.70/hour**

		Utilization per day			
		0.5 PEVs	1 PEV	1.5 PEVs	2 PEVs
		15 e-mi	30 e-mi	45 e-mi	60 e-mi
		5.1 kWh	10.2 kWh	15.3 kWh	20.4 kWh
Project cost	$ -	$ 4,144	$ 8,287	$ 12,431	$ 16,575
	$ 1,000	$ 2,706	$ 6,850	$ 10,994	$ 15,137
	$ 2,000	$ 1,269	$ 5,413	$ 9,556	$ 13,700
	$ 3,000	$ (168)	$ 3,975	$ 8,119	$ 12,263
	$ 4,000	$ (1,606)	$ 2,538	$ 6,682	$ 10,825
	$ 5,000	$ (3,043)	$ 1,101	$ 5,244	$ 9,388
	$ 6,000	$ (4,481)	$ (337)	$ 3,807	$ 7,951
	$ 7,000	$ (5,918)	$ (1,774)	$ 2,369	$ 6,513
	$ 8,000	$ (7,355)	$ (3,212)	$ 932	$ 5,076
	$ 9,000	$ (8,793)	$ (4,649)	$ (505)	$ 3,638
	$ 10,000	$ (10,230)	$ (6,086)	$ (1,943)	$ 2,201

c) **$145/month/PEV subscribed**

		Utilization per day			
		1 PEV	1 PEV	2 PEVs	2 PEVs
		15 e-mi	30 e-mi	45 e-mi	60 e-mi
		5.1 kWh	10.2 kWh	15.3 kWh	20.4 kWh
Project cost	$ -	$ 10,869	$ 8,302	$ 19,171	$ 16,604
	$ 1,000	$ 9,432	$ 6,865	$ 17,734	$ 15,167
	$ 2,000	$ 7,994	$ 5,427	$ 16,296	$ 13,730
	$ 3,000	$ 6,557	$ 3,990	$ 14,859	$ 12,292
	$ 4,000	$ 5,120	$ 2,553	$ 13,422	$ 10,855
	$ 5,000	$ 3,682	$ 1,115	$ 11,984	$ 9,418
	$ 6,000	$ 2,245	$ (322)	$ 10,547	$ 7,980
	$ 7,000	$ 807	$ (1,759)	$ 9,110	$ 6,543
	$ 8,000	$ (630)	$ (3,197)	$ 7,672	$ 5,105
	$ 9,000	$ (2,067)	$ (4,634)	$ 6,235	$ 3,668
	$ 10,000	$ (3,505)	$ (6,072)	$ 4,797	$ 2,231

3.2 Fueling-Cost Benchmarks: MUD Charging and Gasoline Equivalents

This subsection provides benchmarks to facilitate the comparison of the driver costs of various fueling alternatives. Table 3-4 begins with the price of refueling at the four different per-hour recharging price levels described above for Table 3-1. Recall that pricing level 1 is a "breakeven" level that covers the cost of electricity. Table 3-4 then translates those prices into the dollars-per-electric-mile equivalent, using MUD-charging base-case assumptions. It also shows equivalent prices for electricity (per-kWh) and gasoline (per-gallon), representing the fueling alternatives facing a resident driver. 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 baseline of 41.1 mpg.

Table 3-4. Fueling Cost Benchmarks: Per-hour MUD Recharging

Pricing Level[a]		$ per electric mile	Electricity equivalent	Gasoline equiv., CV[b]	Gasoline equiv., (plug-in) hybrid[c]
1.	$0.65/hour actively charging	$0.06/e-mi	$0.19/kWh	$1.72/gal	$2.60/gal
2.	$1.00/hour actively charging	$0.10/e-mi	$0.29/kWh	$2.65/gal	$4.00/gal
3.	$1.35/hour actively charging	$0.13/e-mi	$0.39/kWh	$3.58/gal	$5.41/gal
4.	$1.70/hour actively charging	$0.17/e-mi	$0.49/kWh	$4.50/gal	$6.81/gal

[a] Each pricing level (1–4) provides the same amount of cost-recovery potential (Table 3-1)
[b] CV=conventional vehicle = 27.2 mpg [10]
[c] (plug-in) hybrid = 41.1 mpg [9]

Table 3-5 adds the per-kWh and per-month pricing structures to the picture of the four different pricing levels described above. Recall that the cost-recovery potential achieved at each price level is nearly the same across pricing structures: "breakeven" at level 1, >$1,000 at level 2, >$3,000 at level 3, and >$5,000 at level 4. As seen in the second column of Table 3-5, each price level is also roughly equivalent on a dollars-per-electric-mile basis—roughly 6¢, 10¢, 13¢, and 17¢ per electric mile, respectively.

Table 3-5. Fueling Cost Benchmarks: Per-kWh, Per-hour, and Per-month

Pricing Level[a]	$ per electric mile	Electricity equivalent	Gasoline equiv., CV[b]	Gasoline equiv., (plug-in) hybrid[c]
1. Breakeven prices			*"A Steal"*	*"Incentivizing"*
Electricity cost ($0.164/kWh, yr 1)	$0.06	$0.16/kWh	$1.52/gal	$2.30/gal
$55/month	$0.06	$0.18/kWh	$1.71/gal	$2.58/gal
$0.65/hour charging	$0.06	$0.19/kWh	$1.72/gal	$2.60/gal
2. Low prices			*"Incentivizing"*	*"Cheap"*
Electricity cost + $0.10/kWh	$0.09	*$0.26/kWh*	$2.45/gal	$3.70/gal
$85/month	$0.10	$0.29/kWh	$2.64/gal	$3.99/gal
$1.00/hour charging	$0.10	$0.29/kWh	$2.65/gal	$4.00/gal
3. Medium prices			*"Cheap"*	*"Uncompetitive"*
Electricity cost + $0.20/kWh	$0.12	*$0.36/kWh*	$3.37/gal	$5.10
$115/month	$0.13	$0.39/kWh	$3.57/gal	$5.40/gal
$1.35/hour charging	$0.13	$0.39/kWh	$3.58/gal	$5.41/gal
Gasoline price (~CA 2012 average)	$0.15	$0.43/kWh	*$4.00/gal*[d]	
4. High prices			*"Equivalent"*	*"Forget it"*
Electricity cost + $0.30/kWh	$0.16	*$0.46/kWh*	$4.30/gal	$6.50
$1.70/hour charging	$0.17	$0.49/kWh	$4.50/gal	$6.81/gal
$145/month	$0.17	$0.49/kWh	$4.51/gal	$6.81/gal

[a] Each pricing level (1–4) provides the same amount of cost-recovery potential (Table 3-1)
[b] CV=conventional vehicle = 27.2 mpg [10]
[c] (plug-in) hybrid = 41.1 mpg [9]
[d] http://articles.latimes.com/2013/jan/01/business/la-fi-gas-prices-20130101

Compared to a conventional vehicle, the "breakeven," $0.00/kWh-markup scenario in Table 3-5 illustrates that covering only the marginal cost of average residential electricity presents the resident driver with a low gasoline-equivalent price ($1.52/gal), and thus a large incentive to drive a PEV and charge at home. Even covering markups of up to roughly $0.20/kWh ("medium price") provides financial motivation, and a $0.30/kWh markup ("high price") is only slightly more than California gasoline. Recall that the $0.30/kWh markup was assumed as the base case as necessary for the MUD station owner/operator to cover roughly $5,000 of total project costs. Acknowledging that the driver may consider some additional private or social value (e.g., from the convenience of residential charging, parking or other associated benefits, increased zero-emission/oil-free travel, etc.), this nevertheless might represent a reasonable maximum markup that the MUD site host could expect residents 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 residential charging at prices at or below roughly $1.35/hour or $115/month, respectively (scenario group #3, "medium prices").

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 charging appear relatively less favorable to these drivers. Using the sales-weighted, EPA-rating average of roughly 41.1 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, those drivers might only regularly fuel on electricity if prices are kept at or below price level 2—or $1/hour, $85/month, or a $0.10-markup—as highlighted in Table 3-6.

Table 3-6. MUD Recharging Competitive Price Threshold, Hybrid Baseline[a]

Pricing Level 2[b]	Gasoline equiv.
Electricity cost + $0.10/kWh	$3.70/gal
$85/month	$3.99/gal
$1.00/hour actively charging	$4.00/gal

[a] (plug-in) hybrid = 41.1 mpg [9]

[b] provides $1,000–$2,000 worth of cost-recovery potential in all cases

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 charging than a Volt driver, who in turn might view scenario-group-3 price levels as uncompetitive.

It should further be noted that several all-gasoline hybrids without plug-in capability (e.g., from Toyota and Ford) also 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 Toyota Prius has an EPA-rated fuel economy of 50 mi/gal. Thus, even an all-battery EV driver might choose to drive their PEV less in favor of their regular gasoline-only Prius if 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 that produced $3.37/gal relative to a conventional vehicle. The additional key input not discussed in the previous uncertainty analysis is the 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).

Monte Carlo and bounding analyses indicate the point estimates of fuel costs are reasonable, though the range produced extends to much higher (less competitive) gasoline-equivalent prices than illustrated in Table 3-4. Uncertainty in the costs of electricity contributed roughly seventy percent of the uncertainty in the fuel cost estimate, whereas assumed electric vehicle efficiency contributed a little over twenty percent and gasoline vehicle efficiency a little less than ten percent.

This analysis suggests that the benchmarks presented above are reasonable so long as electricity costs are near the average value of $0.1640. As electricity costs increase toward $0.37/kWh, the financial incentive to even the driver with an inefficient conventional vehicle vanishes.

4. Conclusions

This analysis finds significant opportunity for recharging facility cost recovery at prices that resident drivers might find financially motivating. Prices on the order of $0.36/kWh (including electricity costs and markup), $1.35/hour-of-active-charging, or $115/month allow recovery of roughly $3,000–$4,000 in station investment per vehicle served under the baseline assumptions examined herein. This investment may not be sufficient to cover costs at in wide range of MUD environments (e.g., those that require parking-lot trenching or that have inadequate electrical panel capacity or long distances between the panel and desired charging locations). Further, 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, residential charging prices might have to be kept below $0.26/kWh, $1.00/hour of active charging, or $85/month. These levels provide only roughly $1,000–$2,000 worth of cost-recovery potential per vehicle served.

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 a 15-mile electric range, 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 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 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. This is true across pricing structures, but is dramatic with each additional subscriber to the per-month structure. However, this might prove challenging given potential costs due to evening on-peak electricity costs 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 in MUDs.

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