Electric Vehicle Transportation Center

Cost Analysis of Workplace Charging for Electric Vehicles

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1 Executive Summary

This report examines the life-cycle costs associated with the operation of electric vehicle supply equipment (EVSE) and the impact that plug-in electric vehicle (PEV) charging may have on commercial building electricity cost. This study assumed that a utility electric meter was attached to each charging station and that 10 kWh of energy was required to replenish the energy consumed during a typical 35-mile daily work commute. Residential electricity costs were assumed to be $0.128/kWh. Commercial electric utility rates for a non-demand rate class were assume to be $0.10/kWh while costs for a commercial demand rate class are $0.06/kWh plus a monthly peak demand cost of $11/kW. Through a life-cycle assessment of typical EVSE equipment, including first cost and maintenance and operating costs, it was found that AC Level 1 or 2 workplace charging can be similar to or lower in cost than charging at home. The following table presents the per vehicle charging session costs over a 10-year period with a comparison of the cost of electricity. The EVSE is assumed to be fully utilized if used throughout the workday or underutilized if used only once per day.

Table 1. 10-Year Life-Cycle and Electricity Costs for PEV Charging Stations

Station Type (10 kWh's/day per vehicle)	Per Session Life-Cycle Costs			
	Fully Utilized		Underutilized	
	Life-Cycle	Electricity Cost[1]	Life-Cycle	Electricity Cost[1]
AC Level 1 – R	*$1.79*	*$1.28*	*$1.79*	*$1.28*
AC Level 1 – C	$1.53	$1.00	$1.53	$1.00
AC Level 1 – D	$1.79	$1.29	$1.79	$1.29
AC Level 2 – C – No fee	$1.32	$1.00	$2.60	$1.00
AC Level 2 – C – Fee	$2.24		$6.28	
AC Level 2 – D – No fee	$1.67	$1.39	$5.07	$3.77
AC Level 2 – D – Fee	$2.59		$8.75	
DC Level 2 – D	$2.39	$1.26	$30.15	$11.16
DC Level 2 – T	$2.75		$35.93	

R – residential, C – commercial non-demand, D – commercial demand, T – commercial demand with new transformer
No fee – no annual or per payment processing fees, Fee – annual or per payment processing fees
Fully utilized: AC Level 1 – 1 vehicle per day, AC Level 2 – 4 vehicles per day, DC Level 2 – 16 vehicles per day
Note: [1] – dollar values represent year 1 actual cost

The cost to charge a PEV at home using an AC Level 1 charging station is $1.79 per charging session while charging at work would cost $1.53 if utility demand charges were not part of the electric bill or $1.79 if demand charges were included. Charging the PEV at higher power levels (e.g. AC Level 2 or DC Level 2) can result in much higher costs when charging stations are used only once per day. The underutilized costs shown in Table 1 are representative of how some EVSEs are presently operated.

Workplace charging stations could also be deployed where the charging station electrical connection is made to the facility electrical system thereby eliminating the dedicated electric utility meter. In this case costs for AC and DC Level 2 charging stations may be lower than this life-cycle assessment indicates. However, if the use of the workplace charging station does coincide with the facility's monthly peak demand, then the costs presented here are reasonably accurate. One key finding of this analysis was that electric utility demand charges can greatly increase charging station operating costs for underutilized equipment. If the facility demand charge can be minimized or avoided then workplace charging could ultimately be the lowest cost option.

2 Introduction

Owners of PEVs predominantly charge their vehicles at home[1,2] and this tendency may be more for convenience. Although only a small percentage of PEV owners charge away from home, a large majority of those away-from-home charging events occurred at work. A recent analysis of the National Household Travel Survey data shows that over fifty percent of PEV owners would likely charge their vehicle when the traction battery state-of-charge drops below 50% and between 10 and 30 percent of these drivers may choose to charge at the workplace.[3]

Workplace charging would provide a basic infrastructure to encourage PEV adoption. When using both at-home and workplace charging, the electric-only range of PEVs can be extended[4]. When at-home chargers are not available, for example apartment complexes, workplace charging would provide a convenient location for PEV owners. The business owner could also promote workplace charging as an employee benefit. Additionally, workplace charging is a viable site for future vehicle-to-grid applications, where the building power demand may be decreased through utilization of the energy within the PEV battery.

PEVs offer a far greater efficiency than the conventional internal combustion engine (ICE) powered vehicle. In 2016, the fuel economy for midsize ICE-based vehicles ranged from 13 to 59 MPG, while electric midsize vehicles ranged from 84 to 114 miles per gallon gasoline equivalent (MPGe)[5]. The increased fuel economy for electric vehicles is due to the improved efficiency of the electric motor, as well as the enhanced energy conversion efficiency of battery technologies over combustion cycles. For the consumer, this increased efficiency provides an opportunity to significantly reduce transportation costs. The purpose of this report is to illustrate total costs associated with recharging PEVs as a function of electricity prices and station utilization.

The costs associated with PEV charging are the electricity used to charge the vehicle, the equipment needed to provide the electricity, charging station maintenance and revenue collection, if applicable. Of these costs, electricity is the major variable and depends upon the location of the workplace charger and therefore the utility company electricity rates.

2.1 Electricity Charges

To understand charging equipment operating cost, a discussion of utility electricity charges is required. For residential customers, the cost of electricity is based on a per unit energy (kWh) rate. Utility rate structures vary and cost per kWh can either be constant throughout the day (non-time-of-use), vary based on time of day (time-of-use), or vary based on usage (inclining block). Within the U.S. almost all residential utility rates are constant.

For commercial customers, the cost of electricity is also based on a per kWh basis, but the facility can be additionally charged on a per unit power (kW) basis which is referred to as a demand charge. The two most common commercial rates are referred to as non-demand (kWh-only charges) and demand (kWh plus kW charges) utility rate categories. Commercial customer energy costs are somewhat less than residential customers. For example, the EIA reports for May 2016 that the average residential customer is charged $0.128/kWh while commercial customers are charged $0.1025[6].

In addition to paying energy costs, the commercial demand rate class also pays a monthly charge for the maximum demand incurred during the billing period. Demand charges vary throughout the United States, from less than $1/kW to over $100/kW. The average demand charge in the United States (from the Utility Rate Database) is $8.62/kW. Depending on the site, demand charges can represent more than 50% of the total monthly electric bill. Using one Florida utility company as an example, residential rates are about $0.12/kWh while commercial rates are $0.10/kWh when demand charges are not applicable or $0.05/kWh plus an added demand charge of about $10/kW.

For this analysis, it is assumed that the commercial (non-demand) customers pay $0.10/kWh, while the commercial (demand) customers pay $0.06/kWh and $11/kW. The electricity cost assumptions used in this analysis could be higher or lower than actual electricity rates depending on geography and the rate class chosen or necessitated based on usage. Other electricity rate structures, such as time-of-use rates, can increase electricity costs by over five times when energy is consumed during on-peak periods. Time-of-use rates were not considered in this report. See Appendix A for an example of several different electric utility rate structures. Consult local utility electric rates for exact pricing and method used for calculating demand charges.

2.2 Electric Vehicle Supply Equipment (EVSE)

Commercially available PEV charging stations come in three basic forms: AC Level 1 (1-2 kW AC), AC Level 2 (2-20 kW AC), and high speed DC chargers (up to 20-100 kW DC). These charging stations provide either an alternating current (AC) or direct current (DC) through the charging cable to the vehicle. Charging stations external to the vehicle provide higher charge rates, however, they come at higher first (capital and installation) costs and added maintenance costs. Higher charging rates (and cost) are achieved with DC fast chargers, although this type of charger is mainly used to facilitate long-distance travel and will rarely, if ever, be used for home or workplace charging.

Figure 1. AC Level 1 or 2

An AC Level 1 charging cable is provided with each electric vehicle. This cable plugs into the vehicle on one end using a J1772 plug[7]. The other end of the cable plugs into a standard 120 volt convenience receptacle as shown in Figure 1. Between these plugs is a charge controller which communicates with the vehicle to determine the rate at which the vehicle traction battery is charged, the point at which charging has completed, and diagnostics of the charging session. The maximum AC Level 1 charging rate is 1.9 kilowatt (kW).

Figure 2. AC Level 2

AC Level 2 charging cords are available that can be plugged in to 240 volt outlets, and that use the same connector type for the vehicle. These cables are often limited to a maximum of about 3 kW. Stationary AC Level 2 charging stations are mounted on a wall or post and can provide a charging rate up to 19.9 kW. However, the AC charging rate of any vehicle is limited by the vehicle's on-board AC/DC converter, currently 3.3 kW for plug-in hybrid electric vehicles (PHEV) and 6.6 kW or higher for battery electric vehicles (BEV). Many AC Level 2 charging stations provide about 6 kW of power and are sold on-line or at local home improvement stores. The example in Figure 2 is somewhat portable given that the charging station plugs into a receptacle instead of being wired directly to the building's electrical system, although hardwire systems are available. These low cost charging stations are also less likely to require payment for use. Payment systems increase the capital cost of AC Level 2 charging stations and may also require annual fees and/or per session payments required for processing fees (see Networking costs in Table 5 for average annual values).

Figure 3. DC Fast Charger

DC charging stations, aka "DC Fast Chargers", charge PEVs at a much higher rate, with DC Level 1 rated for 40 kW (80A) service, and DC Level 2 rated for 100 kW (200A) service. As the name implies, it charges the vehicle by suppling DC current directly to the battery. These charging stations include an AC-to-DC converter, are large and require permanent installation (see Figure 3) and typically include some form of payment system.

The rates at which these different chargers operate and the time to complete a full charge are shown in Figure 4. Each charging profile was measured using a 2013 Nissan Leaf BEV. The Nissan Leaf traction battery holds approximately 20 kWh of useful energy. The rate at which the vehicle traction battery is charging is shown as a solid line. The dotted line represents the percent state-of-charge of the vehicle traction battery. The DC fast charger provides a nearly fully charged traction battery in about 30 minutes. This type of charging station begins at a high rate of charge and then reduces the rate of charge after about 15-minutes (for this battery size). The average charge rate over a 30-minute period is lower than this charger's 45 kW nominal power rating. The AC Level 2 charger is somewhat slower and provides a steady rate of charge for about three hours up to a near fully charged battery. The AC Level 1 charger provides the slowest rate of charge and takes about 20 hours to fully charge the battery.

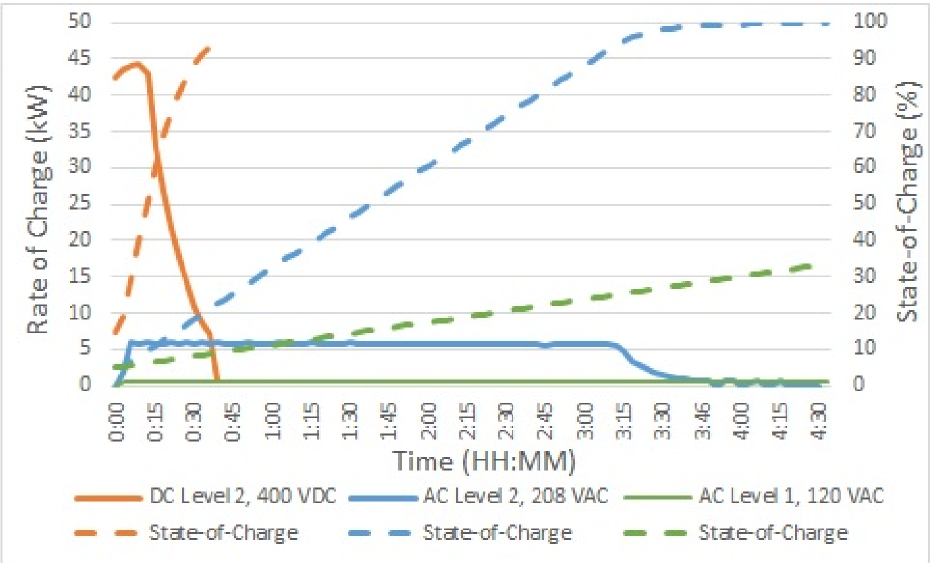

Figure 4. Charging Station Operating Characteristics

2.3 Workplace Charging

The first question to be addressed is which type of charging station is most applicable to use for workplace charging? The amount of time a vehicle is available to charge and the cost of electricity are important factors in charging station selection. For applications where the vehicle remains parked for long periods of time (i.e. long "dwell times"), a slow Level 1 charging rate can provide sufficient energy transfer. As dwell times decrease, higher charging rates are warranted. For vehicles that are driven during the workday (e.g. fleet vehicles) a faster DC charging rate may be necessary in order to accommodate the vehicles' driving needs.

If consumers mostly charge their vehicles at home and use an existing standard 120 volt electrical outlet, then costs associated with recharging their vehicle are based solely on electrical energy cost with only moderate costs attributed to maintenance when a receptacle requires replacement. Charging at home using a standard 120 volt electrical outlet (AC Level 1) is a rather slow process yielding approximately 3-4 miles of range per hour of charge. For an overnight charge lasting eight hours or more, this rate may be sufficient for typical daily travel needs. However, longer daily miles will require higher recharging rates. Therefore, consumers may feel more comfortable having the ability to charge their vehicle more rapidly, for example using an AC Level 2 charging rate via a 240 volt plug or low-cost AC Level 2 charging station. At AC Level 2 charging rates a vehicle can recover approximately 20 miles of range per hour of charge. Of course, choosing the higher charging rate increases equipment first cost and, at times, electricity cost.

Workplace charging offers the advantage of allowing PEV owners to charge their vehicle while at work. This makes a lot of sense given that the vehicle is parked regularly, in the same location, for an extended period of time. The fact that employee vehicles are parked for extended periods of time could also allow employers to select a range of charging equipment based on individual driver's needs. Since nearly 80% of drivers travel less than 50 miles per day[3], an AC Level 1 charger could provide about 30 miles of charge over 8 hours which may be sufficient for a majority of workplace charging events.

If consumers charged their vehicle at work, the operating costs associated with workplace charging are equipment capital and installation costs, operating and maintenance costs, and electricity costs. These costs can vary widely based on charging station selection and utility electrical rates.

3 Charging Equipment Operating Cost

A cost analysis is performed using the three charging stations previously described. For this analysis, the AC Level 1 charging station is assumed to be available at any residential or commercial site. The AC Level 2 charging station is assumed to be subject to commercial electric utility rate structures (although this technology could also be used in a residential application). Given the high rate of charge, DC Level 2 chargers are assumed to be subject only to the commercial demand rate category where monthly demand charges apply.

For this analysis the charging stations are assumed to be utilized throughout the workday as shown in Figure 5 and Table 2. The utilization periods are spaced equally throughout the day with a 1 hour break period for lunch. For this analysis, AC Level 1 has a 1.3 kW charging rate and is able to only charge one vehicle per day while the AC Level 2 station charges at a rate of 6 kW and can easily accommodate four vehicles (each at different times). A DC Level 2 charger is assumed to be able to service 16 vehicles each day given the high rate of charge at 45 kW. For purposes of calculating demand charges, although the DC Level 2 charger has a peak power output of 45 kW, the average charging rate is equal to the arithmetic average of the charging profile, in this case 20 kW (i.e., the station is on for 15 minutes and then off for 15 minutes). The electricity and operating costs associated with these charging profiles are then compared to a single use per day scenario. These costs are also compared to a residential use case where PEVs are charged once per day while parked at home.

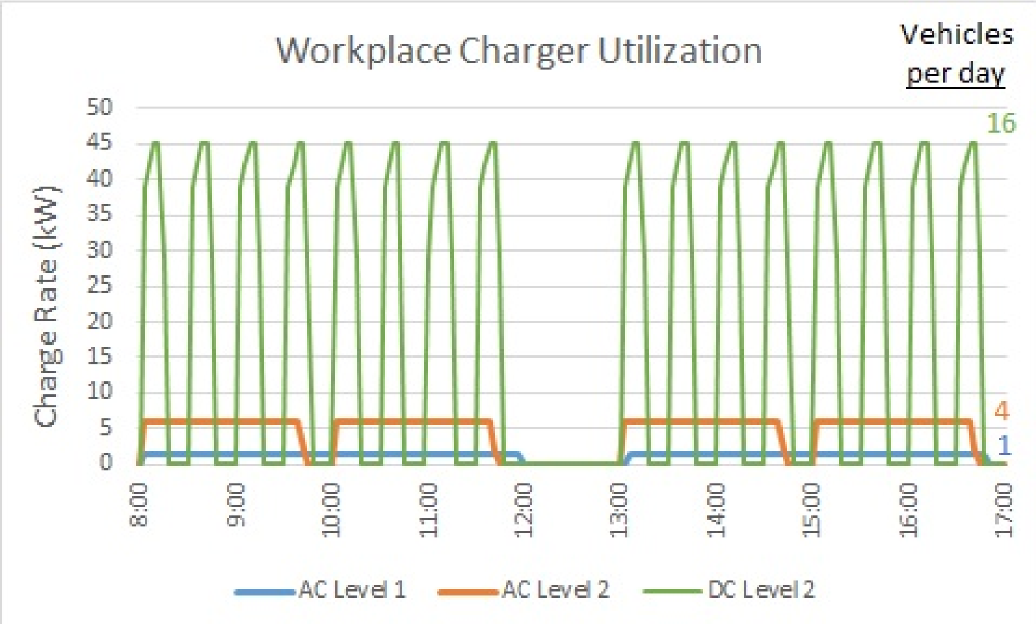

Figure 5. Workplace Charger Operating Profile

Table 2. Workplace Charger Operational Characteristics

Charging Station Type	Maximum Power (kW)	Average Power (kW over 30 minutes)	# of Vehicles Charged per Day	
			Fully Utilized	Underutilized
AC Level 1	1.3	1.3	1	1
AC Level 2	6	6	4	1
DC Level 2	45	20	16	1

This charging station cost analysis includes 7 key assumptions:

- Each charging session consumes 10 kWh, enough for a daily average 35-mile work commute
- Workplace charging only occurs during daytime hours of 8 AM – 5 PM
- Although each charging station has a dedicated meter, residential and commercial electric utility rates are applied (i.e., no special PEV rate class is used to calculate electricity costs)
- Charging stations are operated 5 days per week and 50 weeks per year or 250 charges per year
- Electricity kWh energy charges are assumed to be constant throughout the day
- Electricity kW demand charges are based on a 30-minute averaging window that yields the highest value that occurs once per month
- The underutilized case represents a single use per day for all charging station types. Fully utilized charging stations are represented by 1, 4, or 16 charging sessions per day for the AC Level 1, AC Level 2 and DC Level 2 charging station types, respectively.

The results for a single daily use of a charging station are presented in Table 3. The costs resulting from the commercial non-demand utility rate are lower than the residential results given the lower cost per unit of energy (i.e., $0.10/kWh vs $0.128/kWh). The costs resulting from the commercial demand utility rate are nearly equal to the residential results since the energy and demand costs are each about one-half that for residential. For the AC Level 1 charging station the annual operating costs range from $250 to $322 per year. With 250 charging sessions per year, the per-charging session costs range from

$1.00 to $1.29 across all electric rate categories. For the AC Level 2 charging station using a commercial non-demand rate category the costs are the same as for AC Level 1 at $250/year or $1.00 per session since the amount of energy consumed is the same and electric utility demand charges do not apply.

Table 3. Electricity Costs for Underutilized Workplace Charging Stations

10 kWh's/day per vehicle	Session Statistics		Annual Operating Costs			Per Session Cost
	# of Vehicles/Day	Annual Sessions	Energy	Demand	Total	
AC Level 1 – R	*1*	*250*	*$320*	*$0*	*$320*	*$1.28*
AC Level 1 – C	1	250	$250	$0	$250	$1.00
AC Level 1 – D	1	250	$150	$172	$322	$1.29
AC Level 2 – C	1	250	$250	$0	$250	$1.00
AC Level 2 – D	1	250	$150	$792	$942	$3.77
DC Level 2 – D	1	250	$150	$2,640	$2,790	$11.16

Notes: R – residential @ $0.128/kWh, C – Commercial non-demand @ $0.10/kWh, D – Commercial demand @ $0.06/kWh, $11/kW
AC Level 1 – 1.3 kW @ 7.7 hours, AC Level 2 – 6 kW @ 1.67 hours, DC Level 2 – 20 kW avg. @ 0.25 hours

When utility demand charges are included in the electricity bill, the operating costs for a single daily use charging station increase. Although the energy costs are lower given the lower cost of energy (i.e., $0.06/kWh) there is an added cost for the rate at which energy is transferred. The higher the energy transfer rate the higher the demand charges. At the higher charging rates the demand charges increase the total electricity costs in a disproportionate amount to the energy cost and the cost per vehicle rises significantly. This simplified operating cost analysis shows the troublesome business model for electric vehicle charging stations. Also, these results only highlight the cost of electrical energy and not the capital or recurring costs for the charging stations and do not include the monthly utility fee for the meter. On a per session basis, the cost to replenish the average daily commute energy when demand charges are incurred is $3.77 and $11.16 for the AC Level 2 and DC Level 2 charging stations, respectively.

Had the utilization of these charging stations been higher, for example where multiple vehicles per day accessed the charging station, the costs could be dramatically reduced for the AC Level 2 and DC Level 2 charging stations as shown in Table 4. Monthly utility meter fees are again not included in these results.

Table 4. Electricity Costs for Fully Utilized Workplace Charging Stations

10 kWh's/day per vehicle	Session Statistics		Annual Operating Costs			Per Session Cost
	# of Vehicles/Day	Annual Sessions	Energy	Demand	Total	
AC Level 1 – R	*1*	*250*	*$320*	*$0*	*$320*	*$1.28*
AC Level 1 – C	1	250	$250	$0	$250	$1.00
AC Level 1 – D	1	250	$150	$172	$322	$1.29
AC Level 2 – C	4	1,000	$1,000	$0	$1,000	$1.00
AC Level 2 – D	4	1,000	$600	$792	$1,392	$1.39
DC Level 2 – D	16	4,000	$2,400	$2,640	$5,040	$1.26

Notes: R – residential @ $0.128/kWh, C – Commercial non-demand @ $0.10/kWh, D – Commercial demand @ $0.06/kWh, $11/kW
AC Level 1 – 1.3 kW @ 7.7 hours, AC Level 2 – 6 kW @ 1.67 hours, DC Level 2 – 20 kW avg. @ 0.25 hours

The result of this cost comparison is that the annual electricity cost per vehicle is now similar across all charging station types and electric rate categories except for the commercial non-demand rate category where costs per vehicle are somewhat lower. Even at the higher charging rate for the DC Level 2 charging station, costs on a per vehicle basis are similar. The reason for this is the high utilization of the charging station where the cost associated with utility demand charges are commensurate with energy cost. Also, the demand charges are spread across a large number of vehicles. In general, the cost to replenish the average daily commute energy per vehicle *across all charging station types* is between $1.00 and $1.39. Note that this cost is to replenish the energy required to travel 35 miles per day. For comparison sake, consider what a conventional vehicle would cost to travel that same distance. Assuming a fossil fueled vehicle capable of 25 miles per gallon and $2.00 per gallon fuel cost, annual fuel cost would be $700 or $2.80 per 35-mile commute.

4 Charging Equipment Capital Cost

The Rocky Mountain Institute has presented a range of costs for equipment, materials, installation, permitting and other costs for typical installations of AC Level 2 and DC Fast chargers[8]. Costs were based on whether the charging station would be installed at home, in a parking garage, or curb-side. These costs are summarized here as the average of the equipment type and locations. If a site required a new utility transformer, the utility company would install the equipment and request a one-time equipment plus installation fee. Generalized costs for installing an AC Level 1 charging station receptacle are also included here to provide a broad range of options for workplace charging stations.

Table 5. Workplace EVSE Equipment, Installation and Maintenance Costs

Charger	Average Capital Cost			Recurring Annual Cost	
	Payment Type	Equipment (transformer)	Installation	Networking	Maintenance
AC Level 1	No-fee	$150	$225	$0	$20
AC Level 2	No-fee	$725	$375	$0	$250
	Fee-based	$2,125	$4,875	$400	$250
DC Level 2	Fee-based	$23,500 ($17,500)[1]	$13,125	$400	$1,500

Notes: [1] – added transformer equipment and installation cost when existing electric service requires additional capacity

5 Life-Cycle Costs (LCC) for Workplace Charging

To further understand the overall cost of owning and operating an electric vehicle charging station a life cycle cost analysis must be performed. Using the equipment and annual operating costs presented in the previous tables, a LCC was performed using the following assumptions.

- The general and electricity inflation rates are 1.5% and 1.7%, respectively
- The discount rate is assumed to be 3.5%.
- The straight-line depreciation method is used spanning 7 years at a 20% taxable rate
- Daily station session capacity is assumed to be 1, 2, 4, 8, 16, 20 and 40 as appropriate
- The monthly electricity demand for the DC Level 2 charging station is assumed to increase for the 20 and 40 daily session use cases as 22 kW and 40 kW, respectively, assuming the time between charging sessions is maximized.
- Each charging station is metered by a dedicated electric utility meter with a $10/month fee

5.1 AC Level 1 Charging Stations

For an AC Level 1 charging station, the likely use is in a residential or commercial workplace charging application where a receptacle is installed to service a small number of vehicles. Equipment depreciation was not included for the AC Level 1 charging station. Figure 6 shows the AC Level 1 life-cycle cost for both residential and commercial applications. For the residential application, the present value of the cost for each charging session is $1.79 after 10 years of service. This cost is reduced to $1.47 if one additional vehicle uses the same receptacle after normal working hours. Notice in Table 4 that energy costs alone are $320 per year for 250 charging sessions or $1.28 per session ($1.24 in Net Present Value for year 1).

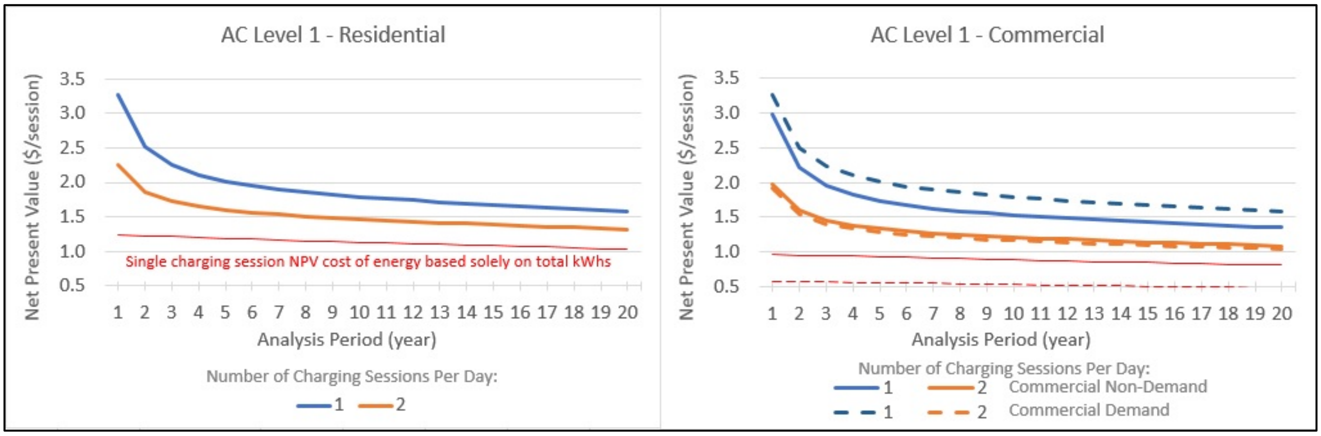

Figure 6. Net Present Value for AC Level 1 Charging Stations

For the commercial application, an electric utility non-demand rate category customer would incur slightly lower cost since the commercial electricity rate is slightly lower. At 10 years the cost is $1.53 and $1.21 for each charging session with 1 or 2 vehicles per day, respectively. If that commercial customer were instead using a utility rate class where demand charges applied, the costs increase slightly for a single vehicle, while costs for two vehicles are lower since the electric demand charge is spread over multiple vehicles. When demand charges are considered, the present value of cost for each charging session for 1 or 2 vehicles is $1.79 and $1.16, respectively. Each figure also shows the per charging session energy only (kWh) cost as a solid (non-demand energy cost, year 1 NPV = $0.97) or dashed (demand energy cost, $0.58) red line. These lines represent the minimum possible electricity cost (i.e., if everything other than electric energy were free including demand charges).

Note that due to the long times required for AC Level 1 charging, only a single vehicle could utilize the charging station during daytime hours of 8 A.M. to 5 P.M. Up to 3 vehicles could potentially use this same receptacle on any given day, however applications where a 2nd or 3rd vehicle would use the same receptacle is limited.

These results show that for AC Level 1 charging stations:

- Workplace charging can be equal to or less expensive than charging at home
- Even when demand charges are considered, low power level charging rates are inexpensive

5.2 AC Level 2 Charging Stations

Although commercial applications could benefit from using AC Level 1 charging stations, in both first costs and operating cost, there are many reasons to consider higher power devices. For example, with limited initial use a single station could serve more vehicles or for retail applications where use of a charging station would draw in customers. Fleet operations may also consider higher charging rates based on vehicle use and scheduling. Regardless of the reason for selection, the costs associated with AC Level 2 is markedly higher than AC Level 1 chargers *when the charging station is not fully utilized*. As charging station utilization increases, the cost per charging session decreases (see Figure 7). The AC Level 2 single daily charging session costs for commercial non-demand rates are $2.60 and $6.28 for the no networking fee and networking fee use cases, respectively. When demand charges are considered the present value of the single daily charging session cost is $5.07 and $8.75 (blue dashed lines) for the no fee and fee use cases, respectively. As previously stated, these charging session costs represent the 10-year life-cycle cost to replenish 10 kWh of energy needed for a 35-mile daily work commute. By comparison, an ICE vehicle could travel the same distance at a cost of $2.80, assuming 25 MPG and $2.00/gal gasoline. This result highlights that although PEV technology is nearly 4-times more efficient than ICE, the high costs associated with underutilized AC Level 2 charging stations can result in transportation costs for PEVs that are more than twice that of ICEs.

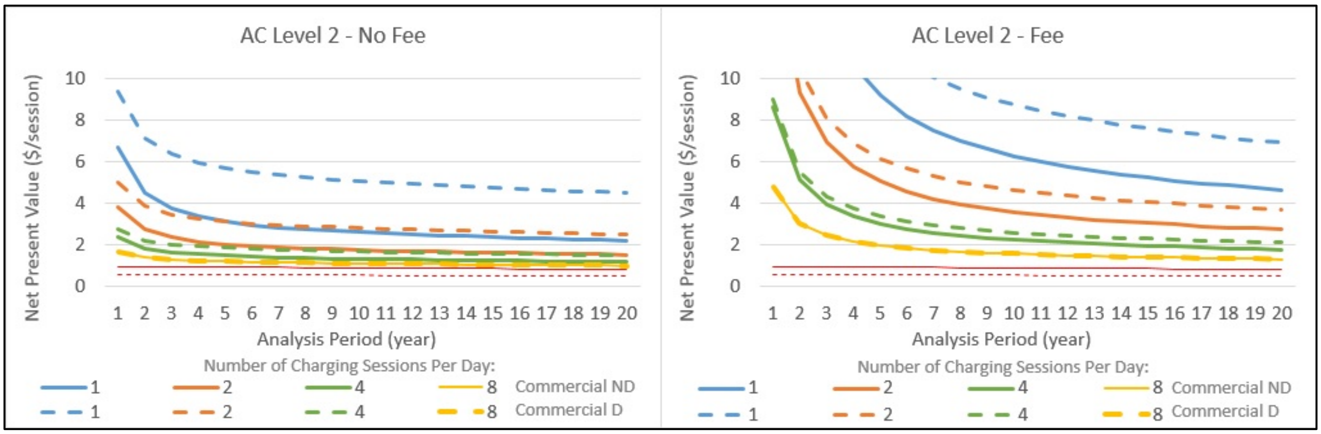

Figure 7. Net Present Value for AC Level 2 Charging Stations

One approach to reducing PEV charging costs is to increase the usage of the charging station. It can be seen from Figure 7 that for four daily charging sessions, the costs for no fee and fee based use cases are $1.32 and $2.24 for the commercial non demand rate class and $1.67 and $2.59 for the commercial demand rate class, respectively.

These results show that for AC Level 2 charging stations:

- Underutilized workplace chargers are more expensive than charging at home
- When demand charges are considered, higher power charging rates may lead to higher operating costs
- Allowing multiple vehicles to use the same charging station can reduce costs below home charging costs when non-fee based equipment is selected

5.3 DC Level 2 Charging Stations

Figure 8 shows the costs associated with DC Level 2 charging. As can be seen, these costs are substantially higher than for AC Level 2 charging, due to the increased cost of the station itself as well as the cost associated with electricity delivery. From this figure, it is apparent that DC Level 2 charging stations could result in increased costs for workplace charging applications, however it is useful to review the life cycle costs as a comparison to the lower-cost alternatives. For this analysis only the commercial demand rate class was considered. The two figures represent the costs when a DC Level 2 charging station is installed where a transformer is not needed or is needed to supplement the existing electrical capacity. Over a 10-year life cycle, the present value for a single daily charging session is $30.15 and $35.93, respectively. The average charging session costs remain high until the utilization exceeds eight sessions per day at $4.24 and $4.96, respectively. To further reduce costs per session to be less than today's fossil fuel cost of $2.80, the number of sessions would need to exceed 15 sessions per day.

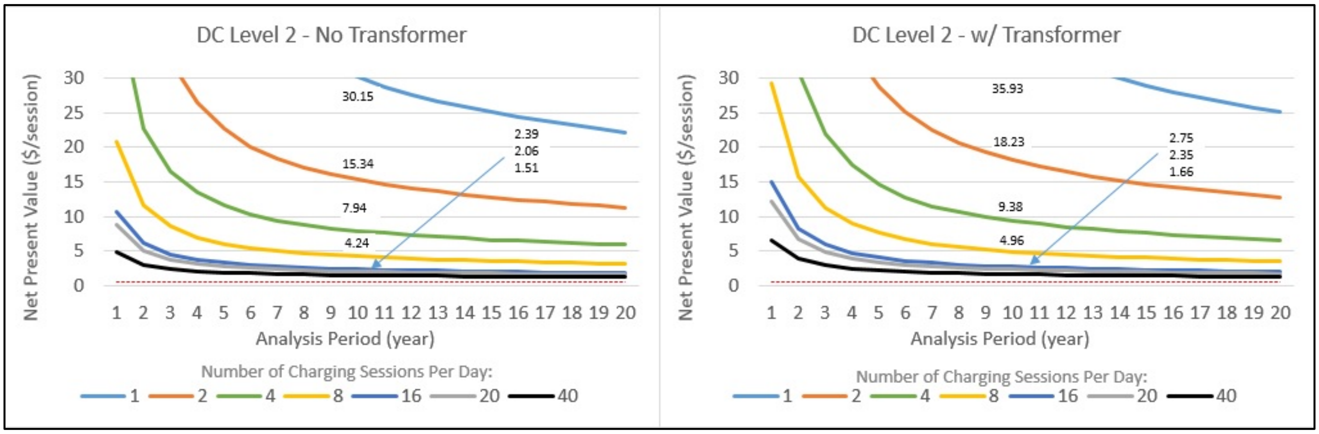

Figure 8. Net Present Value for DC Level 2 Charging Stations

These results show that for DC Level 2 charging stations:

- High first cost and potential high operating cost for underutilized charging stations lead to high electric fuel costs
- High utilization of DC fast chargers can significantly reduce charging session costs to be equal to or less than the cost of fuel for today's fossil fueled vehicles

The charging station life-cycle cost analysis is summarized in Figure 9 and Table 6 for all charging station types and electric utility rate categories. If a charging station is fully utilized the operating costs are reasonably similar across all charging station types. Conversely, if higher power level charging stations are underutilized, especially for the DC fast chargers, operating costs can be extremely high. For workplace charging, where vehicle dwell times are high, the need for higher power level charging stations is limited since the average commute distance can easily be accommodated by AC Level 1 charging. AC Level 2 charging stations could also be used in the workplace if fully utilized. The workplace charger is assumed to be fully utilized if used throughout the workday or underutilized if used only once per day.

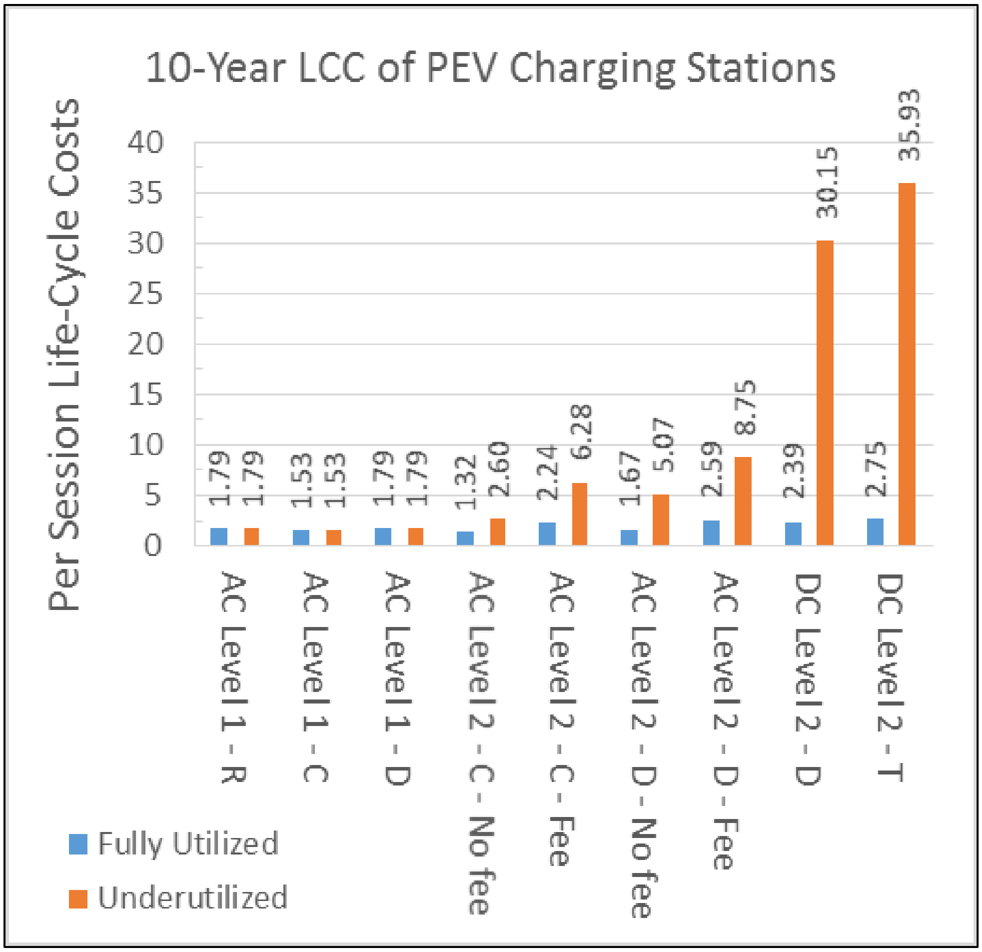

Figure 9. PEV EVSE 10-Year LCC Assessment

Table 6. 10-Year Life-Cycle Cost Assessment of PEV Charging Stations

Station Type (10 kWh's/day per vehicle)	Per Session Life-Cycle Costs			
	Fully Utilized		One Vehicle/Day	
	Life-Cycle	Electricity Cost[1]	Life-Cycle	Electricity Cost[1]
AC Level 1 – R	*$1.79*	*$1.28*	*$1.79*	*$1.28*
AC Level 1 – C	$1.53	$1.00	$1.53	$1.00
AC Level 1 – D	$1.79	$1.29	$1.79	$1.29
AC Level 2 – C – No fee	$1.32	$1.00	$2.60	$1.00
AC Level 2 – C – Fee	$2.24	$1.00	$6.28	$1.00
AC Level 2 – D – No fee	$1.67	$1.39	$5.07	$3.77
AC Level 2 – D – Fee	$2.59	$1.39	$8.75	$3.77
DC Level 2 – D	$2.39	$1.26	$30.15	$11.16
DC Level 2 – T	$2.75	$1.26	$35.93	$11.16

R – residential, C – commercial non-demand, D – commercial demand, T – commercial demand with transformer
No fee – no annual or per payment processing fees, Fee – annual or per payment processing fees
Fully utilized: AC Level 1 – 1 vehicle per day, AC Level 2 – 4 vehicles per day, DC Level 2 – 16 vehicles per day
Note: [1] – dollar values represent year 1 actual cost

5.4 Power Management Strategies

One key finding of this analysis was that electric utility demand charges can greatly increase charging station operating costs for underutilized equipment. Commercial property owners need to evaluate their proposed stations with respect to the number of cars and the electricity and demand costs. If this evaluation shows high electricity demand costs, a lower charging rate should be considered. Alternately, if the facility demand charge can be minimized or avoided then workplace charging could ultimately be the lowest cost option while still allowing for higher charging rates. Methods for mitigating the impact PEV charging stations have on facility electricity use include installation of photovoltaics (PV) or energy storage devices, use of demand management strategies and selection of charging stations with the lowest power output or those with selectable output power.

For commercial applications, eliminating higher PEV charging station electric utility demand costs could be accomplished using a passive or active approach. A simple example of a passive approach is to schedule vehicle charging to occur at times when the facility is known to have a lower peak power demand. For facilities that include PV, charging would only occur during hours of high solar generation. When excess PV energy is available, whether the PV is installed at the facility or elsewhere, the electric vehicle could act as a distributed energy storage device. As PV penetration increases, distributed energy storage devices becomes more desirable. Workplace chargers could help meet this need.

Actively controlling facility peak demand would use techniques similar to those used today for peak shaving and demand limiting. Either the facility operator or an automated energy management system would determine when the PEV charging stations should be disabled to avoid higher electricity costs. Limits on charging rates through demand-side management practices must be balanced against the need of the PEVs to charge sufficiently for the end-of-day commute.

Energy management systems are more common in today's commercial buildings. These systems could be programmed to disable workplace charging if their use would increase facility electricity costs. Some workplace chargers include a mechanism for remote operational control. For charging stations that have no control capability, a simple electrical switch could be installed to serve the same purpose. Electric utility companies may also benefit from workplace chargers if those charging stations could be remotely controlled. This would allow electric utility companies to use electric vehicles to manage the increasing numbers of distributed generation (e.g., PV and wind) and improve the quality of the electric transmission system.

6 Conclusions

Workplace charging will help to promote transportation electrification. Whether out of necessity or purely for convenience, allowing PEV owners to charge their vehicles while at work provides an alternative to public charging stations and allows PEV charging to occur at a location where the vehicle is regularly parked for long periods of time. The amount of time an employee is regularly parked also allows for selection of the most cost effective charging rate. Although this analysis presented three common PEV charging rates, intermediate charging rates are possible. For example, a part-time employee might have a short commute that could be accommodated at an AC Level 2 rate of 3 kW. Choosing the lowest charging rate possible would guarantee the lowest possible electricity costs. This analysis assumed that only the commute energy would be replaced on a daily basis. However, in the event of longer daily travel or shorter dwell time, a slightly higher charging rate could be chosen to more fully charge an employee vehicle while still providing the lowest possible costs. This suggests that when an employer is considering installation of on-site charging stations, an analysis of potential employee usage may be prudent in order to assess the impact on the building energy profile. On an individual case basis, either the business owner or the employee could provide the financial support to create such an infrastructure.

This analysis found that the cost associated with AC Level 1 workplace charging can be equal to or less than the cost to charge the vehicle at home. While AC Level 2 charging provides a higher charging rate, the costs are economical only when the charging station is fully utilized. Regardless of the station type, workplace charging can be economical if the electric utility demand charges can be minimized or eliminated. Commercial demand charges apply only when the facility electricity needs exceed some minimum power requirement, usually 20 or 25 kW. A small business may not qualify for a commercial demand electricity rate, however, adding multiple PEV charging stations could increase the facility maximum power demand sufficiently to require a change to a commercial demand rate category.

The costs associated with PEV energy transfer (i.e. kWh) will always be part of the total life-cycle cost equation, however the total costs must also consider the demand charges that are specific to the particular electric utility rate structure at the charging facility. The costs associated with electric utility demand (i.e., kW) can be addressed up to a point. For a small number of vehicles, the demand costs can usually be mitigated through scheduling or active control. For larger numbers of vehicles, for example a large commercial application, adding to the facility's existing peak demand may be unavoidable. In this case this analysis helps define the limits of those costs.

7 Acknowledgments

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APPENDIX A – Example Electric Utility Rate Schedules

Utility electricity rate structures vary widely across the U.S. Residential, commercial and industrial consumers require a broad range of services depending on the time-of-use and the need for power. To see the variety in electricity rates, different types of rate categories are presented here. Florida has several choices with the most common being residential. Commercial general service non-demand, commercial general service with demand, and commercial service time-of-use rates are also popular categories. One California non-demand rate and several electric vehicle specific rates categories are shown. The electricity rates for a commercial pilot program for electric vehicle charging in Hawaii are also shown. The large general service electricity cost in Michigan has a rather high demand charge while energy costs are of the lowest presented.

Table A-1. Example Electric Utility Rates

<table>
<tr><th>State / Utility / Rate</th><th>Period</th><th>Customer ($/Month)</th><th>Demand ($/kW)</th><th>Summer ($/kWh)</th><th>Winter ($/kWh)</th></tr>
<tr><td>FL FPL RS-1</td><td>All</td><td>7.87</td><td>NA</td><td colspan="2">0.08 (<1000kWh)
0.10 (>1000 kWh)</td></tr>
<tr><td>FL FPL GS-1</td><td>All</td><td>7.75</td><td>NA</td><td colspan="2">0.09</td></tr>
<tr><td>FL FPL GSD-1</td><td>All</td><td>20.24</td><td>10.42</td><td colspan="2">0.05</td></tr>
<tr><td rowspan="2">FL FPL GST-1</td><td>On-Peak</td><td rowspan="2">15.21</td><td rowspan="2">NA</td><td colspan="2">0.14</td></tr>
<tr><td>Off-Peak</td><td colspan="2">0.07</td></tr>
<tr><td rowspan="3">CA SCE TOU-EV-3-A</td><td>On-Peak</td><td rowspan="3">25.43</td><td rowspan="3">NA</td><td>0.36</td><td>0.16</td></tr>
<tr><td>Mid-Peak</td><td>0.17</td><td>0.14</td></tr>
<tr><td>Off-Peak</td><td>0.09</td><td>0.10</td></tr>
<tr><td rowspan="3">CA SCE TOU-EV-3-B</td><td>On-Peak</td><td rowspan="3">25.43</td><td rowspan="3">7.23</td><td>0.33</td><td>0.12</td></tr>
<tr><td>Mid-Peak</td><td>0.14</td><td>0.11</td></tr>
<tr><td>Off-Peak</td><td>0.06</td><td>0.07</td></tr>
<tr><td rowspan="3">CA SCE TOU-EV-4</td><td>On-Peak</td><td rowspan="3">198.79</td><td rowspan="3">13.20</td><td>0.29</td><td>0.11</td></tr>
<tr><td>Mid-Peak</td><td>0.12</td><td>0.09</td></tr>
<tr><td>Off-Peak</td><td>0.05</td><td>0.06</td></tr>
<tr><td rowspan="3">CA PG&E A-6</td><td>On-Peak</td><td rowspan="3">6.11</td><td rowspan="3">NA</td><td>0.55</td><td>NA</td></tr>
<tr><td>Mid-Peak</td><td>0.25</td><td>0.20</td></tr>
<tr><td>Off-Peak</td><td>0.18</td><td>0.18</td></tr>
<tr><td rowspan="3">HI EV-F</td><td>On-Peak</td><td rowspan="3">5.00</td><td rowspan="3">NA</td><td colspan="2">0.32</td></tr>
<tr><td>Mid-Peak</td><td colspan="2">0.30</td></tr>
<tr><td>Off-Peak</td><td colspan="2">0.27</td></tr>
<tr><td>MI DTE LGS</td><td>All</td><td>13.67</td><td>21.89</td><td colspan="2">0.04 (< 200 kWh)
0.03 (> 200 kWh)</td></tr>
</table>

1. Florida Power & Light - Index of Rate Schedules
2. Southern California Edison General Service – Industrial Rate Schedules
3. Pacific Gas & Electric Company – Tariff Book
4. Hawaiian Electric, Maui Electric, Hawai'i Electric Light – Rates & Regulations
5. Michigan Public Service Commission – Approved Electric Utility Rate Book