Overlooking L1 Charging At-Work in the Rush for Public Charging Speed

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***Abstract*—The national emphasis on a massive public Electric Vehicle (EV) charging infrastructure rollout may be contributing more to the perpetuation of range anxiety than it is to mitigating concerns for the average driver. Americans driving habits are based on a century of experience with gas tanks. This experience of *run-until-empty* followed by a *fill-up-to-full* at a public gas station is not how EV's will be used. This legacy places too much emphasis on public high-speed Level-2 (L2) charging. All EV's are designed to be charged overnight from standard 115v outlets, Level-1 (L1), which can give about 32 miles of range for 8 hours charge[1]. The overnight charge plus another 8 hour charge from 115v at work, gives the EV driver a daily range of at least 64 miles. This is well above the national average commute (32 miles round trip) and actually satisfies more than 90% of USA commute distances.**

In addition, mid-range L1 charging to not-fully-full and daily use to not-fully-empty is the best long-life profile for EV batteries. The EV is not intended to out-right replace all gasoline vehicle usage, but is ideal for the commuter who can plug-in at home and plug-in at work. An EV is more like a laptop or cell phone that expects to be plugged in at home and at work when not in use. The commuter vehicle spends at least 16 hours a day just sitting at home and at work, where low-speed L1 charging can exceed 90% of all USA commuter distances. The paper concludes with a list of recommendations for the EV infrastructure rollout.

Keywords- EV charging; Level-1; Level-2; EVSE; payin-to-plugin; charging at work;

I. INTRODUCTION

The recent visibility of Electric Vehicles (EVs) as a key element to our future energy and environmental benefit is confusing to the public due to a century of legacy thinking based on the gas tank and public gas station model. We are seeing the media, the public and the professionals lump EVs into a *"battery tank"* model and then also, to compound all possible charging issues with all possible ramifications when making decisions about the future of the EV infrastructure by this unconscious comparison to the gas car experience. This single focus *public-fill-FAST* approach is detrimental to the acceptance of EV's for applications where they are best, such as commuting.

Data from General Motors, Fig. 1, shows that USA vehicles spend more than 90% of their existence parked at home or at work[2]. That is more than 21 hours a day available for charging while parked. Interestingly, that could equate to almost 85 miles per day using L1 charging alone. Charge infrastructure planning for EV's should fully consider these demographics.

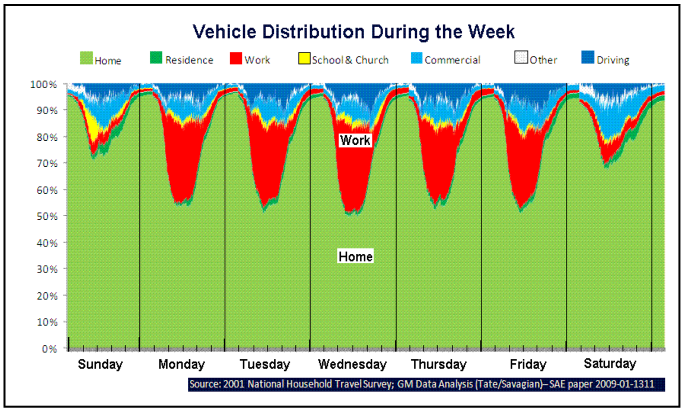

Figure 1. GM data -Vehicle Distribution During the Week [1].

II. CHARGING AT WORK – IDEAL FOR THE COMMUTER

A. *A Battery is not a Gas Tank*

Gas tanks are typically *filled-to-full* and *run-to-empty* and then *filled-to-full* at public gas stations. This is not the EV model as shown in Fig. 2. EV's are typically charged at home and charged at work at lowest cost and where convenient. In the long term, EV's will likely only be charged at the more expensive public charging stations only in extremis or for special situation peace-of-mind.

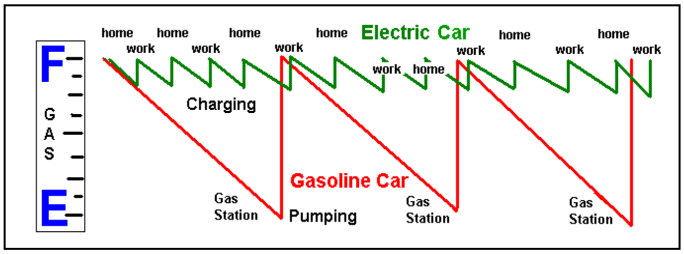

Figure 2. Batteries are charged, at home and at work instead of run till empty and then filled at public chargers.

B. EV Chargingby Location

All EV's come with 115v (L1) charge cords. The GM model for charging the Chevy Volt is shown in Fig. 3. GM assumes the majority of all charging will be at home, the base of the charging pyramid. Next will be routine charging at work and only the tip of the charging pyramid will be at public charging facilities. To this GM pyramid we have added additional notes regarding the probable electricity costs at each level of the pyramid. Notice how looking for public EV charging (at 3 times higher rates than at home) is like looking for $10/gal gas stations; a tactic usually avoided by most drivers.

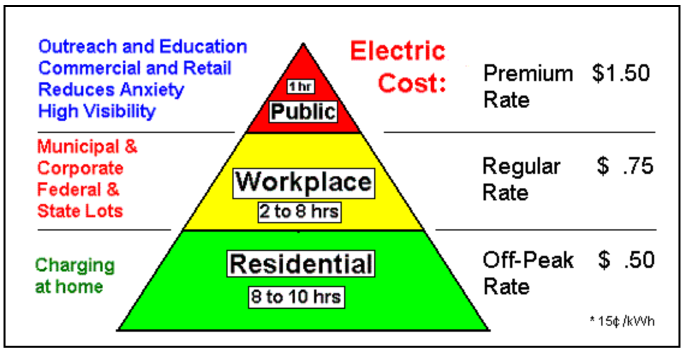

Figure 3. The GM charging pyramid with added notes on electricity costs. [3]

III. CHARGING BASED ON COMMUTE DISTANCE

A great deal can be learned about EV charging by looking at the commute distances for the typical American commuter. US Department of Transportation (DOT) Bureau of Transportation Statistics [4] for one-way distance to work are shown with the broad purple bars in Fig. 4. These data show that about 90% of all USA commutes are 32 miles or less. The narrower green bars have been superimposed to show the low cost to charge (at 15 cents/kWh) for each of these distances. Additionally, prices showing the cost per month for charging-at-work are added below each column in red for each distance.

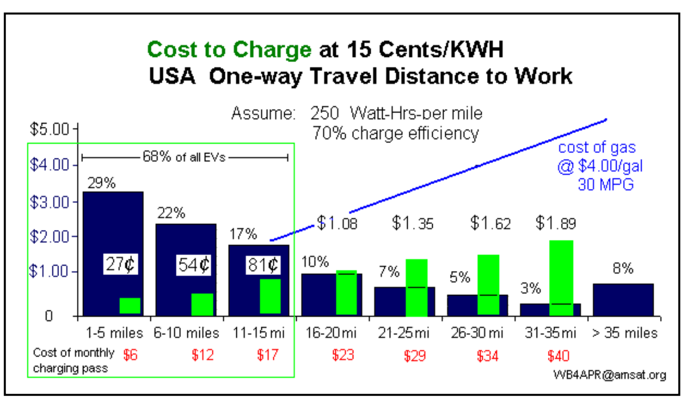

Figure 4. DOT commute distances showing daily and monthly electricity cost.

A. Level-2 Charging for Commuters

In Fig. 5, the same data show how placement of Level-2 chargers at-work or other 8 hour parking lots wastes most of the available charging capacity. The yellow bars show the hours to charge for each of the commute distances. In almost 70% of the cases, the EV is fully charged in under an hour, leaving the L2 charger unavailable to anyone else during the remaining 7 or more hours of the day. This totals to a loss of at least 83% of wasted charging capacity. Even 90% of all commutes are fully charged in under 2 hours. The rest of the day, these chargers are blocked from use by any other vehicles.

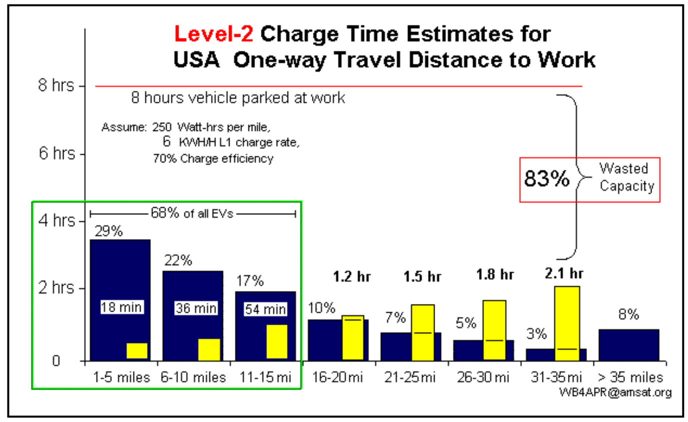

Figure 5. Commute distances with hours-to-charge for L2 chargers showing how most of the L2 charge capacity is wasted (blocked from other's use).

B. Level-1 Charging for Commuters

In contrast, Fig. 6 reveals how 90% of all commuters can fully charge in 8 hours or less on simple 115v outlet power (L1) at work. This data is reliable since vehicles leave home in the morning after an overnight full charge and do not include long ranging errands and activities on the way to work. Those are usually done in the afternoon or evening. Thus, commuter EV's arrive at work with a *charge-need* very well correlated with their known distance to work. The real benefit then, after plugging into only a 115v outlet at work is that they leave in the afternoon or evening with a full charge as well for the remainder of their day, other errands and leisure activities. Even with all of these EV's charging at work on 115v, the L1 charge cords are only using 37% of their overall capacity.

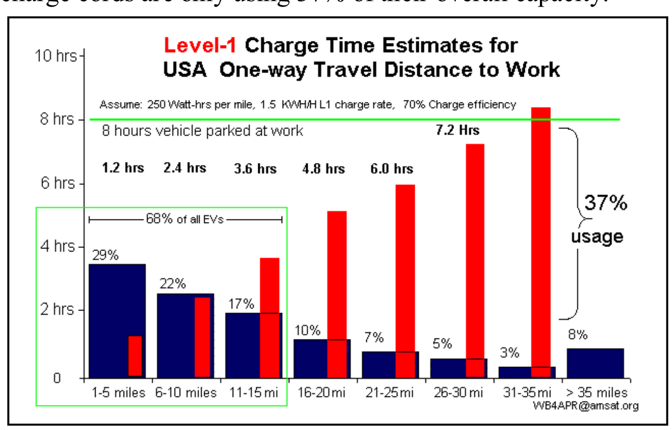

Figure 6. Commute distance data overlaid with the hours-to-charge at-work using convenient 115v outlets (Level-1 charging).

C. Charging distance for the Volt when charged at work.

Assuming the commuter can plug-in at work, the range of her EV can be significantly increased. If she has a short commute and only uses a few miles of range, then plugging in at work is of little benefit since she can only add a few miles before her battery is full again. But the longer her distance to work, then the greater the daily mileage she can gain by charging at work. We have attempted to show this effect in Fig.7. In this figure, instead of showing the percentage of drivers in each distance group by the height of the purple bars, we have shown these percentages by their width.

This allows us then to use the vertical axis to show total mileage available to the EV commuter who plugs-in at work. In this case, we use the example of the 40 mile range GM Volt. On the left, 29% of daily commuters only drive 5 or less miles to work, and so even if they charge at work, their total daily electric range is only 45 miles, with 40 miles of errand range available after work. Few of these drivers will bother to plug-in at work.

For those with longer commutes, their daily range is increased farther because they always charge at-work and leave with a full charge. This is why the purple range available after work (40 miles) remains the same for each category of commuter.

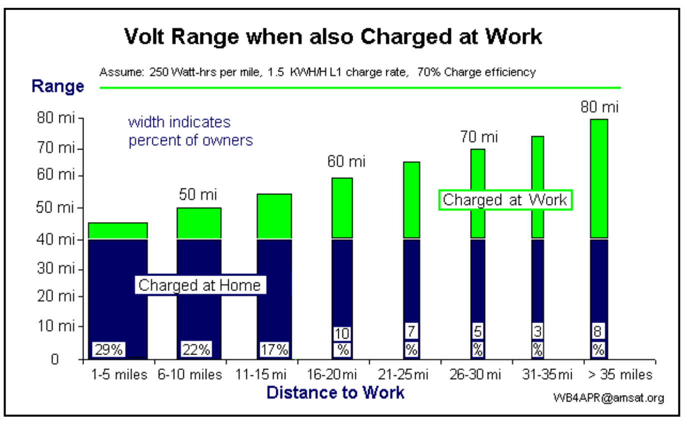

Figure 7. Extended Daily Range of GM Volt when charged at-work.

D. Charging Distance vs Charging Time

Range anxiety and public charging fears are further being perpetuated or misdirected by the common presentation metric of *hours-to-full-charge* as shown in the left hand table of Fig. 8. These hours-to-charge are almost universally quoted when educating (in a negative sense) the public about charging EV's. Other than the short-range Prius PHEV, these hours promote a feeling of inadequacy of simple 115v L1 charging. Instead, this same data can be presented as *miles-per-charge* for 8 hour at-home and at-work charging as shown on the right. When compared to the typical 10 to 15 mile commute for 50% to 70% of all EV owners previously presented, the 8 hour overnight or at-work charge is quite adequate for all EV car models independent of their overall battery capacity. The data show that the size of the battery is not the primary metric for the convenience of L1 charging, but it is the length of the commute.

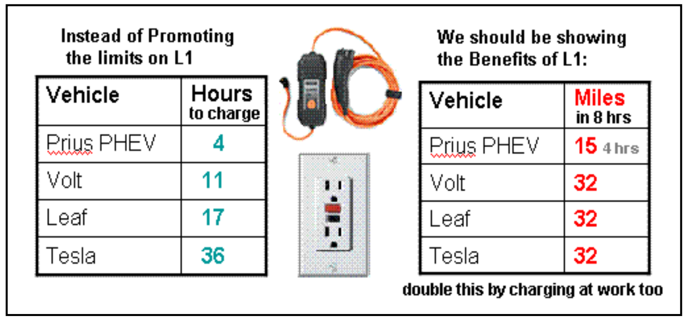

Figure 8. Typical 115v charge times based on battery size (left) –vs -the same vehicles presented in miles-gained per overnight or at-work charge (right).

E. Whats's good for the Battery - Not Fast Charging

Finally, what is good for the EV battery is usually not fast charging. Of the eight recommendations [5] for best EV battery life, five of them are benefited by avoiding fast L2 charging and using more frequent L1 charging instead:

#1. Avoid full charging when you can.

#2. Avoid deep discharging your battery pack.

#4. Minimize the time spent at a high state of charge.

#6. … plug in whenever you can.

#8. To maximize battery life, minimize use of DC quick charging.

IV. Paying for Charging at Work

Due to the public focus on the high costs of L2 fast charging there is an obsessive attention to pricing, payment and usage metering. This payment concern primarily comes from the gas-tank model experience where a fill-up can cost from \$50 to \$75 for a full tank of gas. This payment concern is quite mitigated for the EV where daily charging outside the home generally costs less than a \$1 a day to full charge. This two order of magnitude difference does not normally come across to the average non EV driver.

This misplaced metering and payment concern is driving huge investment in national metering and charging complexity, often costing more per charge transaction than the actual cost of the electricity.

This gas-tank legacy gives a very distorted picture. As shown in Fig. 3, the most an EV can draw from a 115 outlet is only about \$1.80 a day and only if it sits there for 8 hours and only if the battery was driven at least 32 miles to get there. As shown, 87% of commuters will not have that need.

A. Payin-to-Plugin

The simpler approach to the EV commuter car (appliance) charging is to simply pay the employer (or parking lot) in advance for the nominal rate of electricity used for the daily commute to work. A simple monthly charging pass as shown in Fig. 9, can easily be implemented by most employers or parking lots. The cost of this placard would be from $8 to $24 per month for 80% of all commuters using the cost data in Fig. 4.

These payin-to-plugin passes can be managed by the employer as easily as they presently mange parking passes in their employee lots or garages. Enforcement is no more difficult from the process they currently use to manage these lots and handicapped parking spaces now.

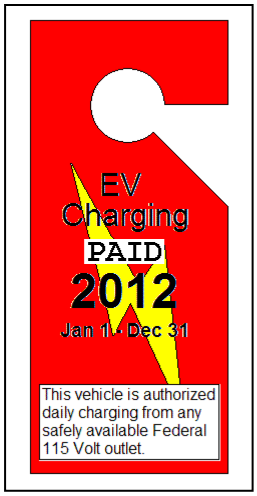

Figure 9. A monthly charging pass costing the same as electricity used is an easy way to implement charging-at-work using existing or future 115v outlets.

V. Charging Infrastructure Considerations

There are a host of considerations with respect to growing the EV charging infrastructure. Since this is a complete break from the century old legacy of the gas-tank model of personal transportation, there is a lot of public misinformation about the breadth and depth of these issues.

A. Charging Problems and Issues

Generally, public documentation and discourse on the EV charging infrastructure issues do not take the effort to distinguish between those issues that apply to Level-2 charging as opposed to any issues that might apply to Level-1. In fact, most of the commonly addressed EV infrastructure charging issues listed below apply only to L2 and generally do not apply to early adopters using L1 charging at home or at work:

- Charging Equipment Cost
- Installation Labor Cost
- New high current wiring Costs
- Larger circuit breaker box often needed
- Metering (Payment System) Costs
- Neighborhood Clustering
- Neighborhood Utility Transformer upgrade
- Grid Loading
- Peak Demands at Peak load
- Charging Speed
- High rates reduce battery life

None of the above issues apply to Level-1 charging from any available 115v standard outlet. Yet almost all of the literature will document these issues without any mention that they only apply to L2 fast charging.

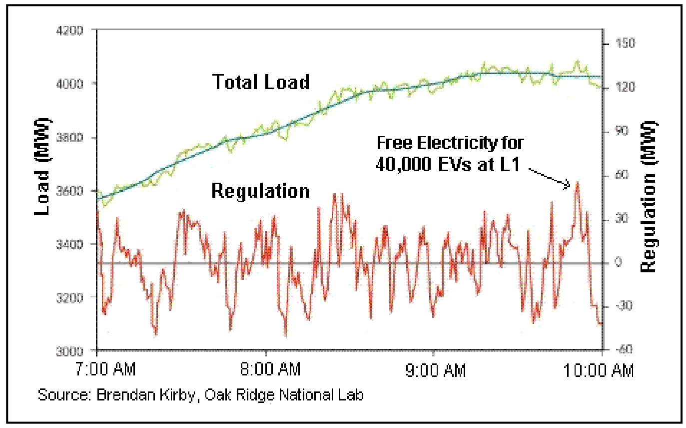

Figure 10. Minute-by-minute Load Regulation can charge thousands of EV's.

B. Charging-at-Work. Easily used for on Peak Load Control

Although charging-at-work is highly desired by the EV owner for maximum range, it would appear to be against the general motives of the utilities that want to avoid additional on-peak daytime loads. But concentrating charging-at-work at major employers gives the opportunity for cost-effective real-time bulk control of instantaneous charging by the utility (or employer) as a means for load leveling. In Fig. 10, the routine minute-by-minute regulation of grid power results in a need to exchange tens of megawatts of real-time loads in minutes[6]. The excess energy in these huge swings can be used to charge as many as 40,000 EVs at no significant additional cost to the utilities.

An entire row of parking lot 115v outlets can be aggregated into multiple time blocks with each having its own simple load control device or timers as shown in Fig. 11. Under the control of the utilities, just like we have today for water heaters and air conditioners, these EV's can provide dynamic load leveling using existing devices. No need to wait for the future smart grid. We can do it now.

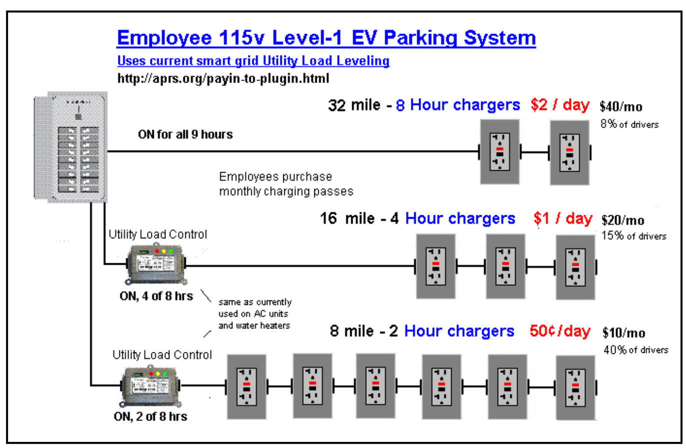

Figure 11. Low-cost Level-1 Employee Charging using Utility Load Control

VI. Recommendations for the Industry

An EV is not a one-for-one replacement for a wide ranging-general purpose gas car. An optimum application for the EV is for the daily commuter with a reasonable distance to work and a place to plug it in. Every EV comes with a standard 115v charging cord for home charging, but almost all public discussion and infrastructure investment is focused not on the convenience of routine 8 hour charging on 115v from standard outlets at home and at work (L1), but on fast public charging (L2). This off-target focus is based on the legacy drive-to-empty and gas-station fast-fill-to-full gas tank model, but is inappropriate for the EV commuter model. The EV model is more of a commuting appliance, to be plugged in at home and at work, than the legacy *go-fill-up-fast-at-a-public-charging-station* experience of the American public.

As an Industry, we should:

- Not oversell EV's as gas car replacements across the board and where inappropriate
- Recognize that charge-at-home and charge-at-work covers 90% of all USA commutes
- Recognize 205 million commuters (67%) have homes with easy access to outlets (single family detached) [7]
- Encourage Employer charging-at-work to double the EV commuter's range
- Avoid public EV charging statements that do not differentiate L2 from L1 charging
- Encourage informal monthly *payin-to-plugin* programs for the ~ $1/day cost of electricity
- Educate the public on the advantages of L1 charging at home and at work and the insignificance of the load and cost
- Encourage L1 charging to avoid peak loads and neighborhood utility clustering problems
- Encourage L1 charging from standard outlets to avoid expensive electrical work
- Encourage L1 charging cords at low cost for sale to the consumer
- Encourage L2 fast chargers only at shorter-duration parking spaces for easy access to many cars a day
- Discourage L2 chargers in long-term/daily lots where 1-hr charged cars block usage for hours or days
- Recognize that most EV charging issues apply mostly to L2 and not to L1 charging
- Recognize that utility load leveling can be easily accomplished in bulk employer lots vs individual chargers all over town
- Educate the public how L1 charging can be better for long battery life than fast charging
- Avoid magnifying L2 issues/concerns/problems where L1 solutions also exist
- Continue full support for fast L2 charging, but not to the extent it undermines public awareness of L1
- Recognize that charging-at-work to extend range has a national security value during the coming petroleum crises
- The 200 Million EV goal in 25 years won't be met with the single minded public L2 approach

VII. Conclusion

The EV is a very significant part of the solution to our future energy, environmental, and national security issues. We must not let misinformation, and public confusion based on a century of *quick-fill-up-gas-tank* legacy thinking undermine or slow this radical new technology.

Nothing in this paper is intended to slow or impede L2 charging initiatives or installation progress. The goal here is to make sure that we do not overlook L1 opportunities in our haste with the speed of L2. As the commuter learns the benefits of EV's and charging at-work, the expensive quick public EV charger will eventually be as little used as the *spare-gas-can-in-the-trunk* is used by gasoline drivers. This is especially true if expensive quick L2 chargers have to charge a premium on the cost of electricity. The value of the EV is in long term lower commuting cost, lower emissions, and improved national security and it is counterproductive to assume that the primary means to get to that state is based on added driving to find public fast chargers that charge more for electricity

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