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Are Taxpayer and Private Dollars Creating Effective Electric Vehicle Infrastructure?

Tom Saxton[1]
[1]*Vice President, Plug In America, 2370 Market Street #419, San Francisco, CA 94114, tom@pluginamerica.org*

Abstract

Since 2009, the US government has awarded over $130 million in grants to fund the installation of electric vehicle charging infrastructure (EVI) through public/private partnerships in projects worth over $260 million. Other public and private dollars are also being used. How effective is the resulting EVI in supporting current and future electric vehicle deployment?

Keywords: BEV (Battery Electric vehicle), business model, charging, education, infrastructure.

1 Introduction

Electric vehicles are hitting the market on a scale never before seen, with nearly every automaker at least talking about producing plug-in electric vehicles. To support the anticipated growth of electric vehicles on a scale large enough to counter the rising global demand for declining oil supplies, hundreds of millions of dollars have been allocated to establish widespread electric vehicle charging infrastructure. How is the effort stacking up against current and anticipated electric vehicle adoption?

2 Why Electric Vehicle Charging Infrastructure?

A 2010 Plug In America study [1] shows that the vast majority, 91%, of electric vehicle charging occurs overnight at the owner's home or at work. Similar results were found by Project Get Ready studying approximately 2,800 LEAFs [2]. Although electric vehicles can be quite capable of handling typical US daily driving using only home or workplace charging, public charging infrastructure serves several important purposes.

2.1 Public Education

Although electric vehicles (EVs) have been around for more than 100 years, and in fact pre-date internal combustion engine (ICE) vehicles, for most consumers electric vehicles are new technology. Public charging infrastructure raises visibility of electric vehicles, and owners report that charging in public is an effective way to start conversations about EVs.

2.2 Extending the Usable Range of EVs

Public electric vehicle charging infrastructure (EVI) increases the range of electric vehicles, both directly and indirectly. Clearly, being able to charge away from home increases the range an EV can be driven in a day. There's also a psychological effect wherein having known charging increases driver confidence and allows increased use of an EV's single-charge range, particularly with the availability of DC Quick Charging [3].

2.3 Establishing the J1772 Standard

EVs produced to satisfy California's Zero Emissions Mandate from 1997 through 2003 used a variety of physical and electrical charging standards. This increased the difficulty and

expense of establishing EVI and was inconvenient to drivers. In January of 2010, SAE adopted the revised J1772-201001 standard for Level 2 EV charging [4]. Quickly deploying large numbers of J1772 stations will help establish a single standard.

3 What is Level 2 EV Charging?

Level 2 charging uses 240V to charge an EV's traction battery. The J1772 standard allows for charging at up to 240V/80A (19.2 kW) although federal grant money used to establish an initial network limits charging stations to a maximum of 240V/30A (7.2 kW).

3.1 Typical Time to Charge

Although the Nissan LEAF requires 8 hours for a 3.3 kW Level 2 charge from empty to full, typical charge times are much shorter. Data released from Project Get Ready [2] shows that the average distance driven per day in a LEAF is 30.8 miles, requiring an average charging time of 2 hours on a weekday (slightly less on weekends).

3.2 Energy Requirements

Also according to the Project Get Ready data, the average daily LEAF charge requires 7.5 kWh of energy, about one third of the energy required for a full charge.

3.3 Battery Size and Charge Time

A 2003 Department of Transportation survey [5] found that the US average round-trip commute is 26.4 miles and that 78% of drivers have a daily commute of 40 miles or less.

Daily charge time depends on average miles driven, vehicle efficiency, and charge rate. The capacity of the vehicle's battery does not affect the time needed for daily charging; it is relevant only for maximum charge times on long drives.

Therefore, the above results can be extrapolated to suggest the average daily charge time needed for any EV of comparable efficiency to be approximately 2 hours regardless of battery size.

3.4 Charge Rate and Charge Time

EVs with an onboard charger capable of using the maximum output from a 7.2 kW station would cut the average daily charge time to under an hour, and vehicles capable of charging at the full 19.2 kW Level 2 rate could do average daily charging in under 30 minutes [6].

4 EV Charging Site Design Considerations

From the EV driver's perspective, charging sites need to be findable, available, and operational. If the driver is in the situation where charging is needed to complete a journey, a charging site that fails to meet any of these criteria is worse than no charging site. Making a detour and using up valuable charge only to fail to get a charge can be a considerable inconvenience. For a site to reliably provide charging, the following considerations must be satisfied.

4.1 Signage

Knowing the location of a charging site from a map may not be sufficient for finding the charging stations. Searching though a large parking garage for unmarked charging stations that can easily be obscured by parked vehicles can be a frustrating and fruitless experience. Charging sites should include signs directing drivers to well-marked stations.

The Puget Sound Regional Council (PSRC) Model Guidance [7], developed in collaboration with Plug In America, recommends standard signage for directional and station signage.

4.2 Parking Policy

The PSRC Model Guidance recommends that charging stations be reserved with signs "No Parking Except for Electric Vehicle Charging." The idea is to convey to drivers that they are not allowed to parking in these spots except when charging an electric vehicle.

4.3 Accessibility

The Americans with Disabilities Act prohibits, among other things, discrimination on the basis of disability in access to public accommodations [8]. Although public EV charging stations have been available in limited areas of the US for over 10 years, the widespread installation of EVI for mainstream, mass-production EVs is new and has not yet been codified in ADA regulations. Recommendations for the number of ADA charging stations are made in the PSRC Model Guidance (July, 2010) [7], and Clean Fuels Ohio and Virginia Clean Cities have released *EV Charging for Persons with Disabilities* (February, 2012) [9].

While there may not yet be many people confined to wheelchairs among the relatively small number of electric vehicles owners, any driver can be

suddenly limited in mobility due to injury and thus in need of, and entitled to, equal access. Site owners need to keep this in mind when designing charging locations, perhaps especially so when accepting taxpayer dollars to defray costs.

5 Grants and Goals

The installation of electric vehicle charging stations is being funded in part by at least two large federal grants and many smaller state and local grants in partnership with other public and private entities.

5.1 The EV Project

On August 5, 2009, ECOtality was awarded a $99.8 million grant from the U.S. Department of Energy to embark on project to install 14,000 charging stations in 18 major cities and metropolitan areas [10]. In June 2010, they were awarded another $15 million by the US DOE.

5.2 ChargePoint America

On June 2, 2010, Coulomb Technologies announced the ChargePoint America program made possible by a $15 million grant funded by the American Recovery and Reinvestment Act. The program makes ChargePoint charging stations available in nine designated regional metropolitan areas of the US.

5.3 State and Local Grants

Numerous state and local grants are also being used to fund EVI. For example, Puget Sound Clean Cities used US DOE ARRA Clean Cities Petroleum Reduction funding to help their partners install 135 charging stations in Washington state.

6 The Blink Network

ECOtality operates the Blink Network of charging stations. As of this writing, the Blink Network web site map lists 1,152 charging stations at 498 sites. For the period from December 25, 2011, through February 25, 2012, the use and availability of public charging stations as shown on the Blink network map were recorded at 5-minute intervals and analyzed. Results of that study are shown in the graphs below.

Figure1 shows the number of available, in use, and offline stations shown on the Blink network by hour and day of week, averaged over the period of the study. For the entire period, an average of 3% and a maximum of 6% of the stations were reported in use on an average hourly basis. On average 25% (1 in 4 stations) were offline, leaving typically about 72% of the Blink stations online and available for use.

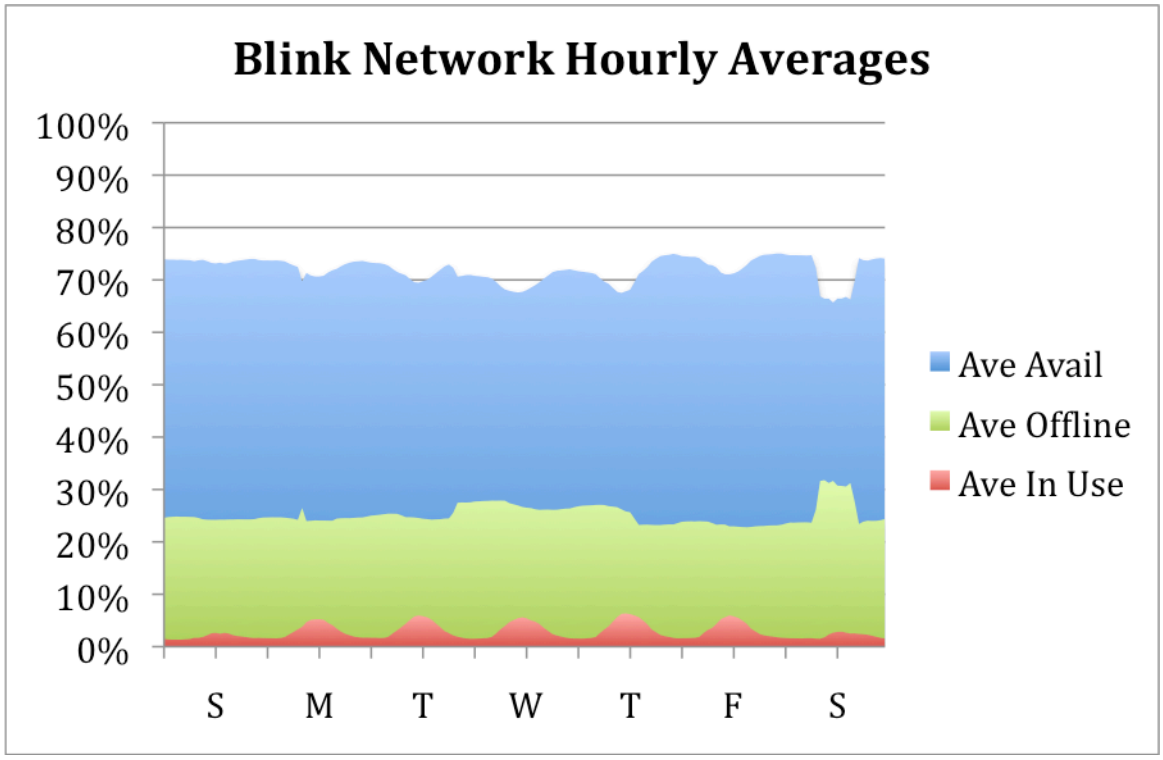

Figure1 Blink Network hourly average usage and availability Dec 25, 2011 - Feb 25, 2011.

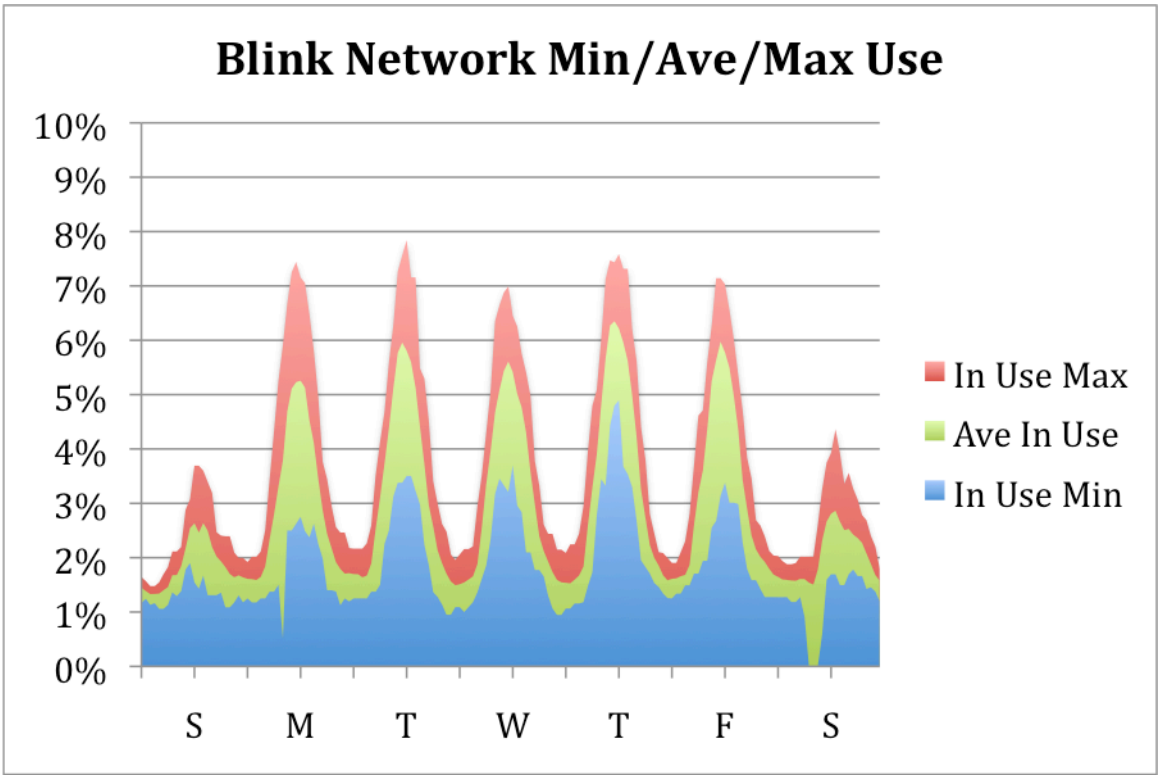

Figure2 Blink Network hourly minimum, average and maximum usage.

Figure2 shows the minimum, average and maximum use levels by day of week and hour over the period of the study. Taking one sample of the Blink map status every 5 minutes, we see peak use levels slightly above 7%.

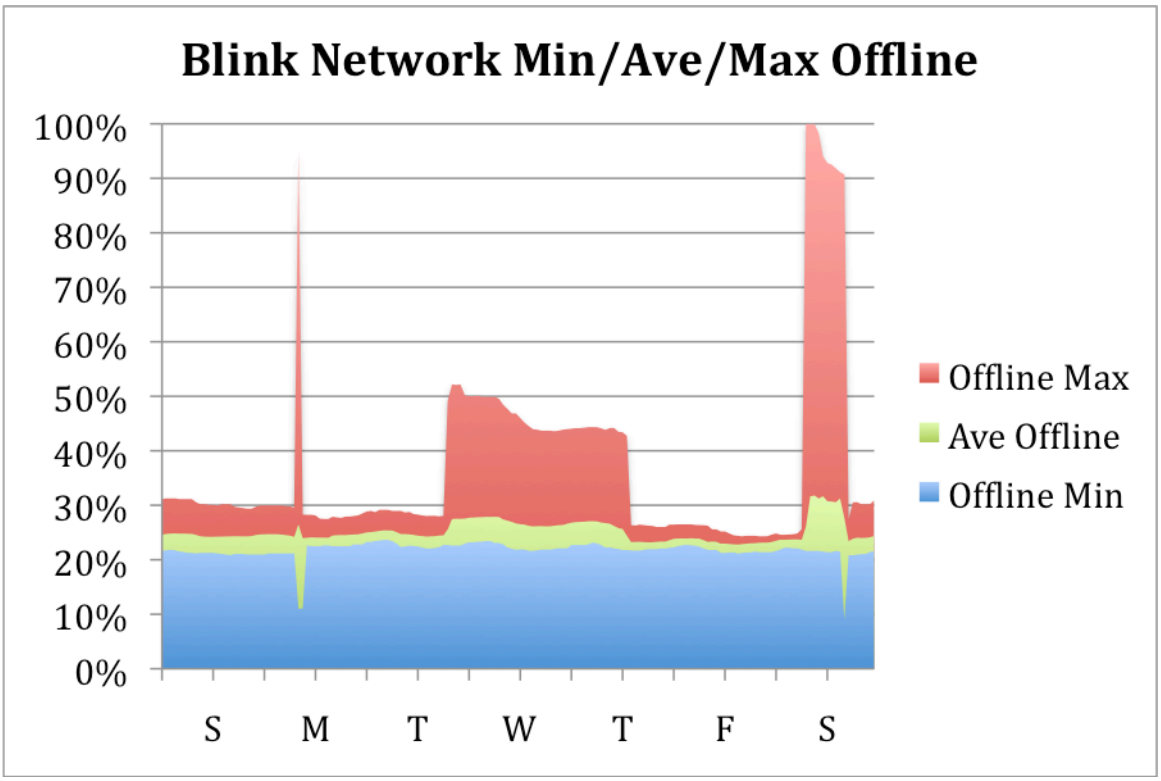

Figure3 Blink Network hourly minimum, average and maximum stations offline.

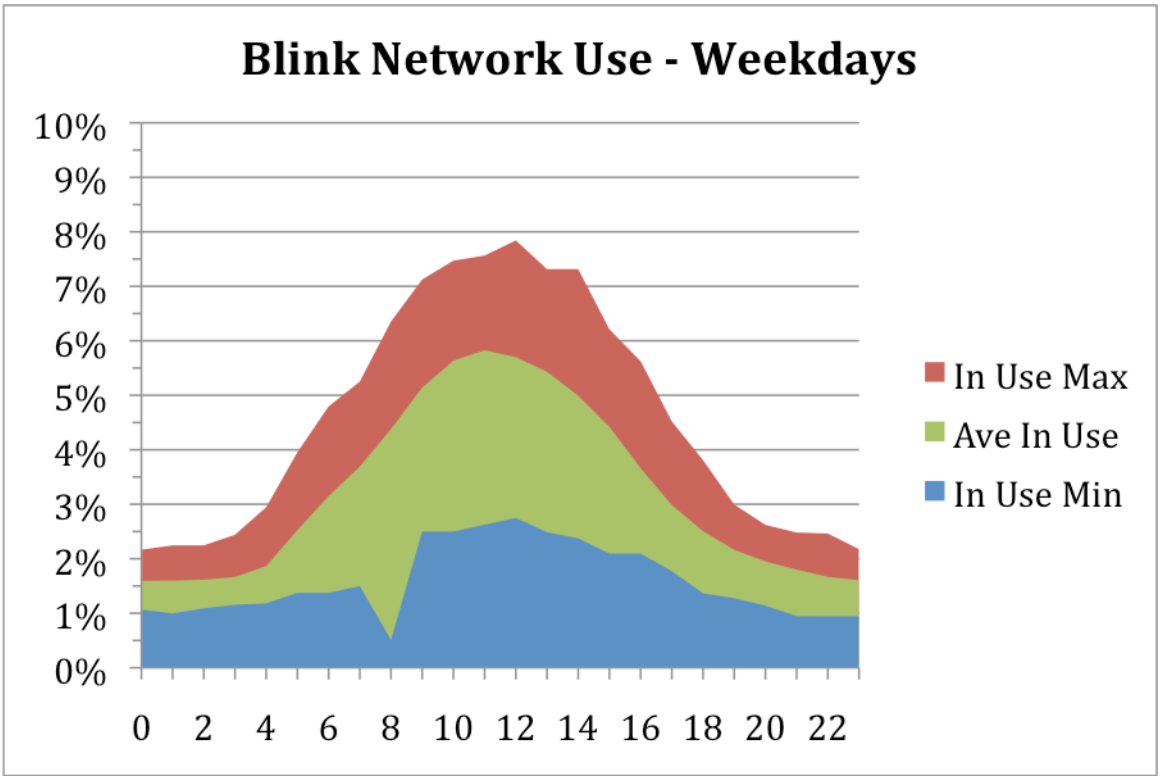

Figure4 Blink Network weekday hourly minimum, average and maximum usage.

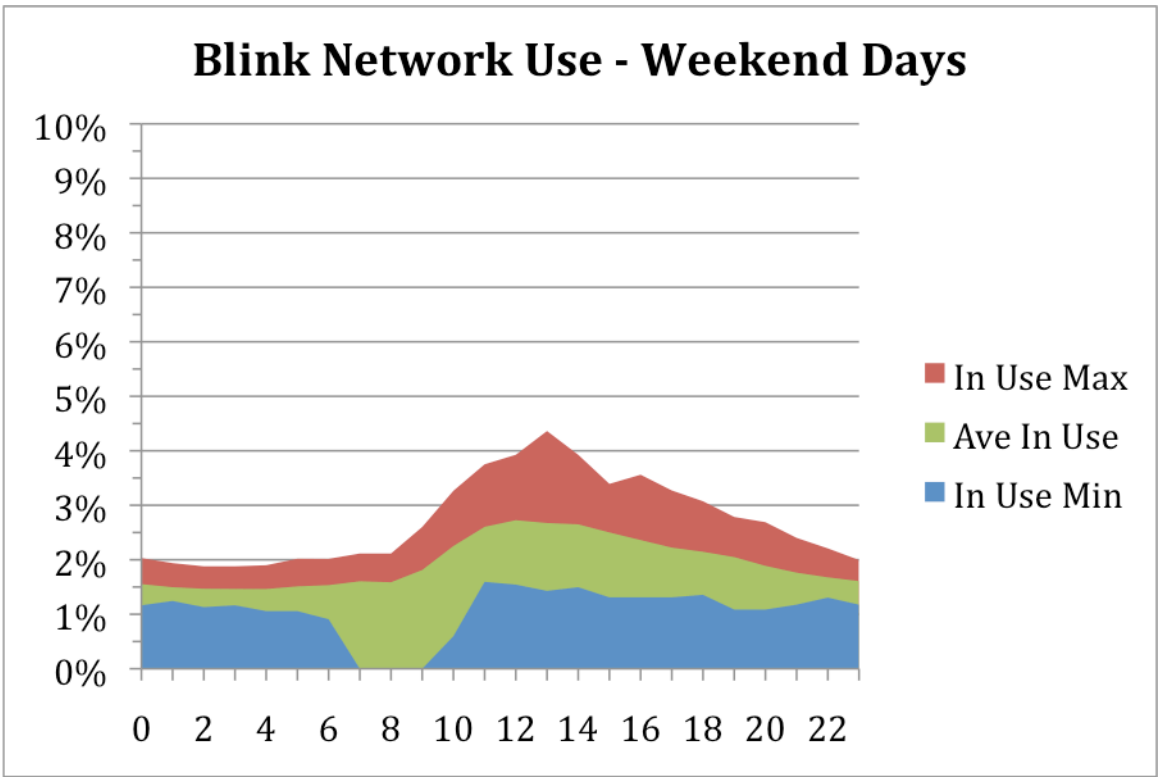

Figure5 Blink Network weekend hourly minimum, average and maximum usage.

Figure3 shows the minimum, average, and maximum offline rate for each hour of the week over the study period. While the average offline rate for the study period was 25%, several widespread outages were reported on the Blink network map during the study period and are

reflected as spikes in the maximum outage rates on the graph. A 90-to-100% outage occurred on Saturday January 28, 2012, from approximately 7:50 AM to 4:30 PM PST, a 20-minute 90% outage started around 8:40 AM on Monday, January 30, and another extended outage from approximately 7:50 PM on Tuesday, February 7 to 1:30 PM on Thursday, February 9, 2012, showed 45% to 55% of the Blink stations offline.

Figure4 and Figure5 show the minimum, average, and maximum network use rates for week days and weekends.

7 The ChargePoint Network

Coulomb Technologies operates the ChargePoint network of charging stations. As of this writing, the ChargePoint network web site map lists 2,441 charging stations at approximately 1,465 sites.
For the period from December 25, 2011, through February 25, 2012, the use and availability of public charging stations as shown on the ChargePoint network map were recorded on 5-minute intervals and analyzed. Results of that study are shown in the graphs below.

Figure6 shows the number of available, in use, and offline stations shown on the ChargePoint network by hour and day of week, averaged over the period of the study. For the entire period, an average of 5% and a maximum of 9% of the stations were reported in use on an average hourly basis. On average, 8% (1 in 12 stations) were offline, leaving typically about 87% of the stations online and available for use.

Figure7 shows the minimum, average, and maximum use levels by day of week and hour over the period of the study. Taking one sample of the ChargePoint map status every 5 minutes, we see peak use levels slightly above 9%.

Figure8 shows the minimum, average, and maximum offline rate for each hour of each day of the week accumulated over the study period. While the average offline rate for the study period was 8%, several brief outages were reported on the ChargePoint network map during the study period and are reflected as spikes in the maximum outage rates on the graph. A 50-minute increase in offline stations peaked at 28% on Friday, Jan 13, 2012, at 9 AM PST. A 55-minute spike peaked at 48% on Wednesday, January 25 at 3 AM. A 4-hour spike from approximately 6:40 PM to 10:30 PM an February 7, 2011, showed the offline rate from 28% to 37%.

Figure9 and Figure10 show the minimum, average, and maximum network use rates for week days and weekends. Note that the ChargePoint network map includes 326 private workplace stations (13%) of the network, plus 200 (8%) that aren't classified as public or private.

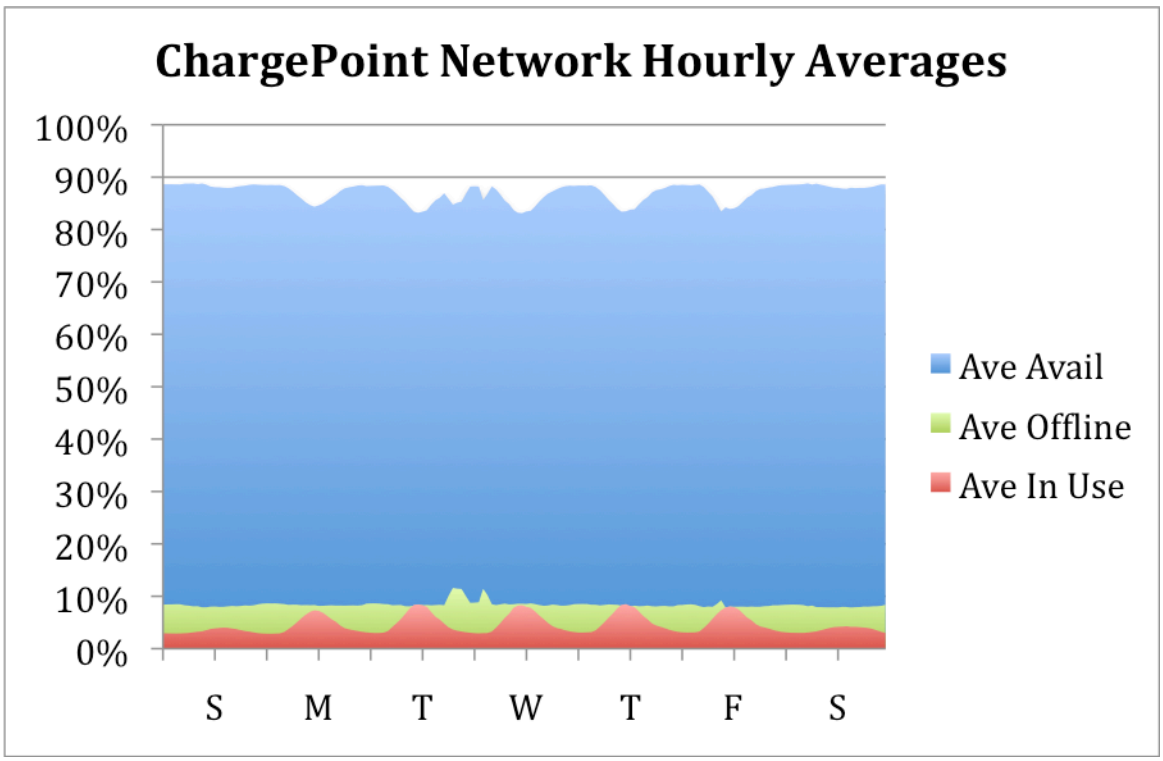

Figure6 ChargePoint Network hourly average usage and availability Dec 25, 2011 - Feb 25, 2011.

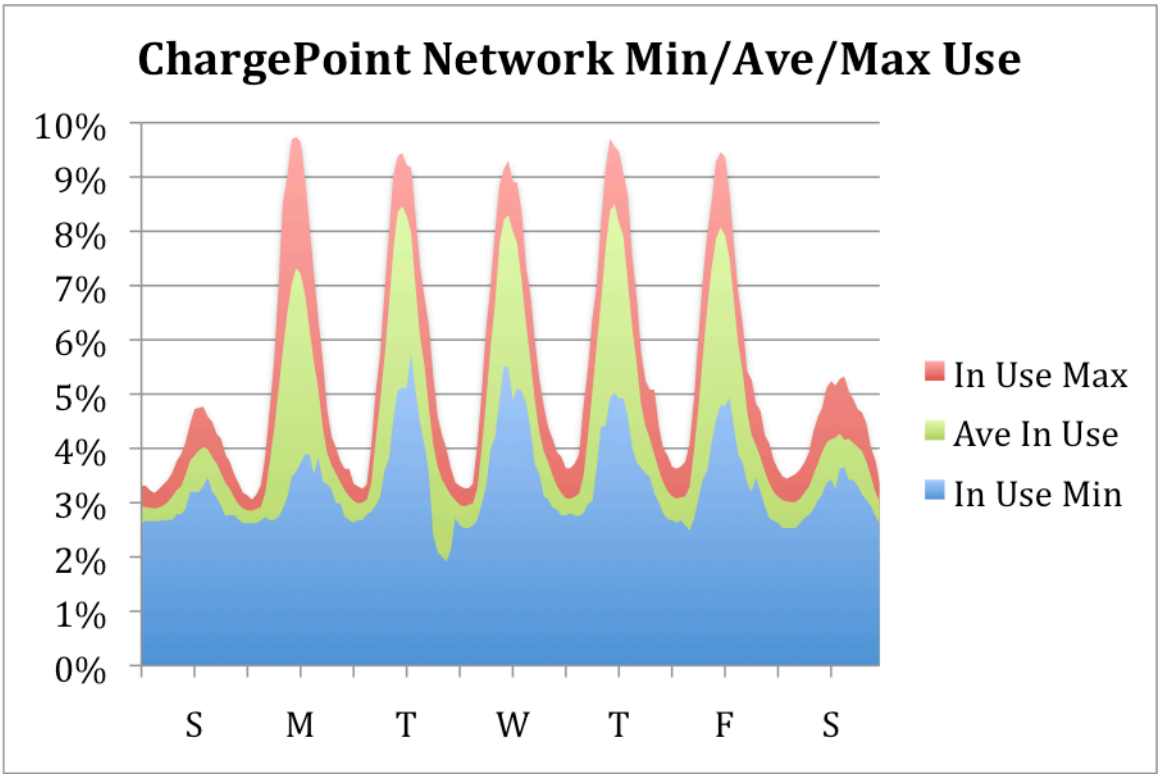

Figure7 ChargePoint Network hourly minimum, average, and maximum usage.

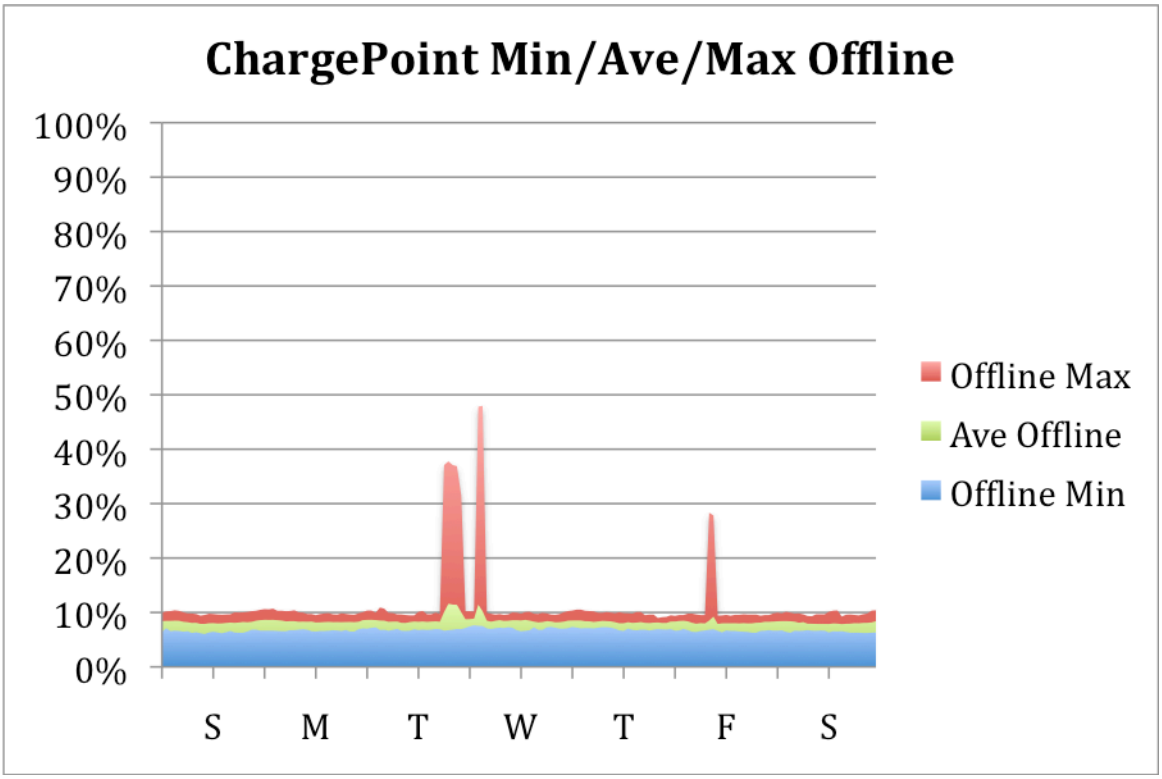

Figure8 ChargePoint Network hourly minimum, average, and maximum stations offline.

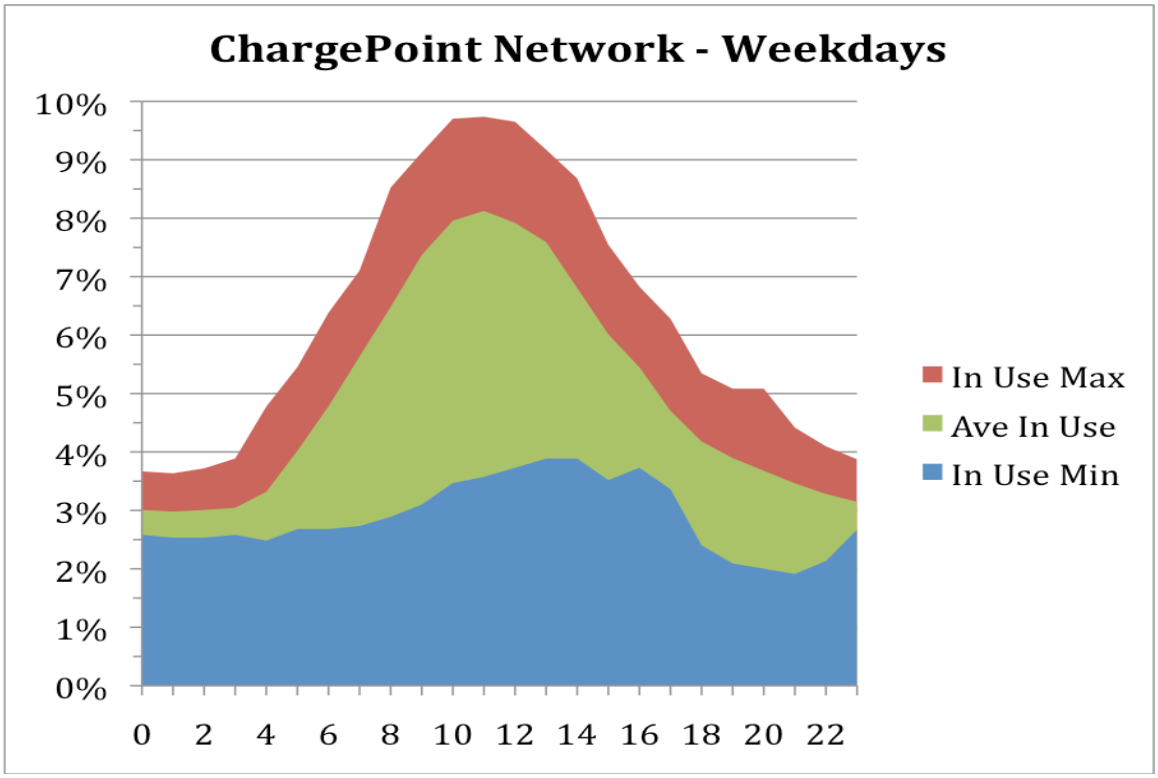

Figure9 ChargePoint Network weekday hourly minimum, average, and maximum usage.

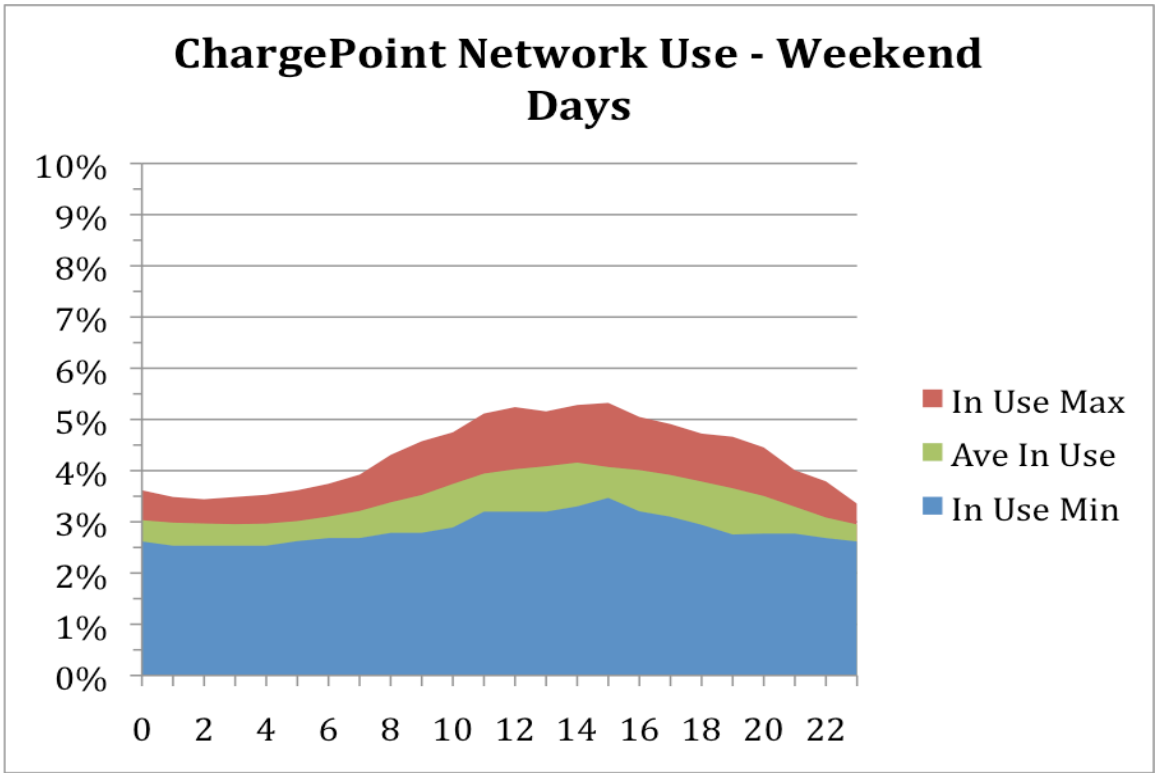

Figure10 ChargePoint Network weekend day hourly minimum, average and maximum usage.

8 Plug In America EVI Survey

In early 2012, the author created a web-based tool to conduct a nationwide survey of charging sites. During the initial phase of the survey, only Blink and ChargePoint stations as listed on their respective web maps were candidates for survey visits, for a total of 1,875 sites comprising 3,608 stations.

EV owners were invited to contribute to the survey which yielded 23 volunteers who made 147 site visits to describe 114 sites and 218 stations in 6 states.

8.1 Charge Available Report Results

Table1 shows the detailed results on charging availability from the site reports. Of 147 reports, 83% reported that charging was available and 17% reported that there was no charging available for a wide spectrum of reasons. The three most common reasons for lack of charging reported were: stations were blocked by ICE vehicles, all available stations were non-functional, and the site could not be found.

8.2 Parking Policy by Station

Table2 shows the reported parking policy signage for each station. Of the 218 stations surveyed, 40% have signs similar to that recommended by the PSRC Model Guidance that prohibit parking except for electric vehicle charging. Another 45% have parking restricted to electric vehicles. This wording can cause confusion about the purpose of the spots, especially for drivers of hybrid vehicles who consider their vehicle to be electric despite not having a way to charge their battery from grid power. A few more stations had the clearer policy of restricting parking to plug-in electric vehicles without mentioning charging, bringing the total up to 88% of stations making some attempt to restrict parking in front of stations to appropriate vehicles.

Table2 Parking Policy by Station

Parking Policy	**Stations**
No Parking Except for Charging	88
PEV Only Parking	6
EV Only Parking	98
Alt Fuel Only Parking	2
Marked w/o any restriction	8
No marking or restriction	16
Total	218

8.3 Access for Disabled Drivers

Survey participants reported that only 3% of stations were accessible from parking spots reserved for vehicles with disabled permits. 5% of sites have at least one station accessible from a reserved location.

Survey participants were also asked to judge if stations were wheelchair accessible even when not reserved for disabled permits. By their judgment, 43% of stations were accessible and 58% of sites had at least one accessible station.

From examining the body of reports, the author believes there is a wide margin of error in these accessibility judgments. Newly released guidance [9] will help improve these judgments, but further study is needed to broaden and validate these results.

8.4 Ongoing Survey

The survey is ongoing. Results with more data will be reported in the future.

Table1 Site Charging Availability Report Summary

Charge Available Result	**Reports**	**Good**	**Bad**
Yes, I did charge.	106	106	
Yes, Level 2 charging appeared to be available.	11	11	
Yes, charging appeared to be available.	5	5	
No, all stations were in use.	2		2
No, all available stations were non-functional.	5		5
No, one or more stations were blocked by ICE vehicles.	5		5
No, there were no open, functional charging stations available.	2		2
No, there is no public access to the site.	4		4
No, I could not find the stations.	5		5
No, for some other reason.	1		1
Level 1 charging was available, but not Level 2.	1		1
	147	122	25

9 Effect of Billing on Usage

As with any product or service, the price affects demand. The available data is examined to quantify the effect of billing on usage and the implications for both site owners and EV drivers.

9.1 Results

The ChargePoint network includes both free (75%) and paid (25%) charging stations. By examining the two classes of billing, some insight is gained in how billing affects use rates.
Comparing free and paid stations, we find that total per-station use at paid stations is only 28% of the free station use on weekdays and 20% on weekends. See Figure11 through Figure14.

9.2 Interpretation

Because ChargePoint bills for time connected, not just time charging, there is a strong incentive to unplug after charging at paid stations but not at free stations. This may exaggerate the implied driver preference for free charging.
Billing rates were also not considered. There may be less difference in use between free stations and stations billed at rates close to the local residential cost of electricity and more difference in use between free stations and those that are billed at 5 or even 10 times the cost of the electricity.
Finally, free charging is known in the EV driver/advocate community as an effective way to engage the public in conversations about electric vehicles, which may also be increasing the use of free charging.
Parking fees are not known for most sites, so some stations that offer free charging still require payment, which could mean the numbers shown here understate the difference in usage.
Other factors such as site location desirability were not controlled in this preliminary study and may also play a role.

9.3 Implications of Billing on EVI

The data suggests that billing greatly decreases usage at EV charging stations. This has both positive and negative implications.

9.3.1 The Downsides of Billing

Reduced usage creates a perception that the stations are not used. This is bad for the site owner that either expected to attract customers or expected to recoup the expense of installing charging through billing. It's also bad for the effort to make EVs more visible to the public for the purpose of encouraging EV adoption through outreach and education.
Site hosts who choose to bill above the marginal cost of providing charging, to recover install costs

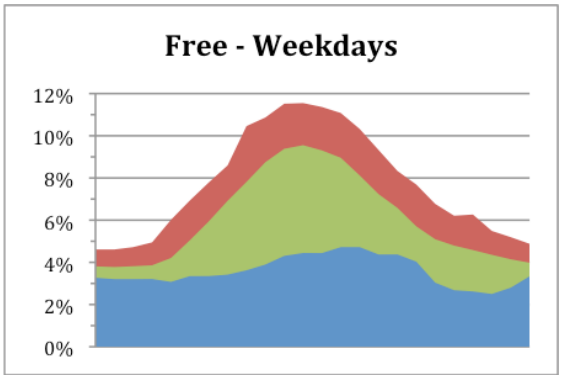

Figure11 ChargePoint Network weekday min/ave/max use rates at free charging stations.

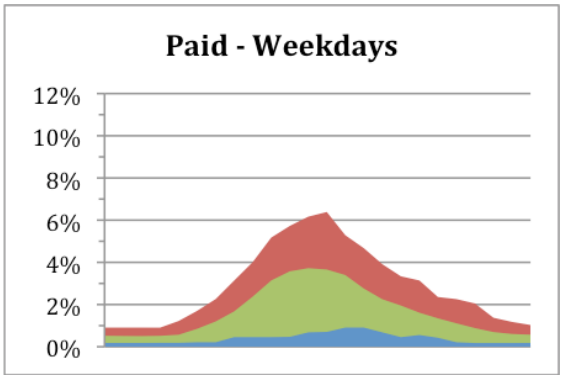

Figure12 ChargePoint Network weekday use min/ave/max rates at paid charging stations.

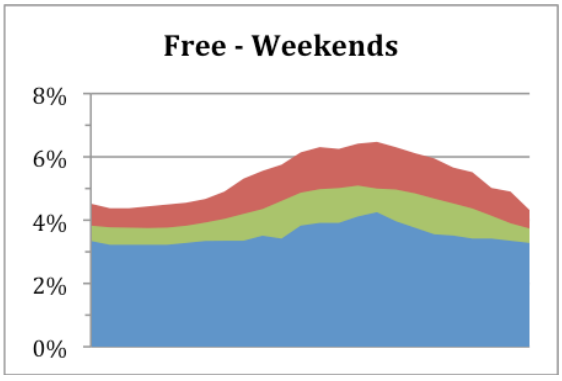

Figure13 ChargePoint Network weekend min/ave/max use rates at free charging stations.

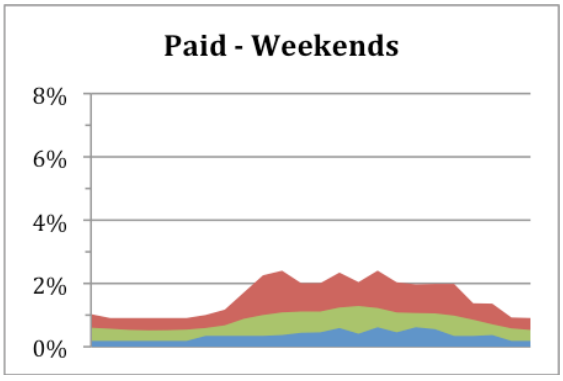

Figure14 ChargePoint Network weekend min/ave/max use rates at paid charging stations.

and/or return a modest profit, may be disappointed if they get very few users and/or get undercut by competitors offering less expensive or free charging.
Sites that bill significantly above the cost of electricity generate feelings of resentment for what is viewed as gouging, especially when the charging stations are perceived to be fully or partially funded by taxpayer dollars.

9.3.2 The Upsides of Billing

Being able to bill for electricity use makes installing charging stations more appealing to many potential site hosts, although it's important to consider other options for return on investment, such as attracting new customers and building goodwill to retain existing customers.
As we get past the early stages of mainstream EV adoption and charging becomes important to more drivers, reducing usage through billing aids in keeping stations open for drivers who really need the charge by discouraging use by those just attracted by free electricity.

10 Additional Data From Map Vendors

Information from two comprehensive charging site map efforts help estimate the total extent of EVI in the US and corroborate some survey results.

10.1 Recargo

Recargo is a charging station map service available through the web at www.recargo.com and also on the iPhone App Store and Android Marketplace.

10.1.1 Charging Availability Reports

The author was able to examine 835 site reports from the Recargo database and found that 13.7% of visits to Blink sites and 8.7% of visits to ChargePoint sites reported that charging wasn't available. Reports for sites that aren't marked for having any networked charging stations showed a 10.3% failure rate. The total average failure rate was 10.0%. This is noticeably lower than what the PIA EVI Survey found.

10.1.2 EVI Size Estimate

The data suggests that the Blink and ChargePoint networks represent about 75% of the EVI in the US.

The Recargo database lists 559 sites not on the Blink or ChargePoint network. Some of those may in fact be Blink sites, which would lower the overall size estimate.

10.2 Open Charge Map

Open Charge Map is an open database of charging sites that is available to anyone who wants to create a charging site map. More information is available at openchargemap.org.

10.2.1 Charging Availability Reports

Unfortunately, the OCM database does not currently have comprehensive check-in data.

10.2.2 EVI Size Estimate

The OCM database contains 1,074 ChargePoint sites, 364 Blink sites, 540 Aerovironment sites, and 1,717 sites with unknown/unclassified station operators. This data suggests that the combined Blink and ChargePoint networks only represent about 40% of the EVI in the US.

11 Conclusion

11.1 Scale and Capacity of Today's EVI

A station that is used primarily during the work day, and is in use 100% of those 8 hours would have a use rate of 33% overall. Stations used primarily in the evenings might be considered fully subscribed if they are used for 12.5% of each day. A site that has appeal for retail hours could support a 50% or higher use rate.
If we assume most sites can be useful 50% of the day, and that it is desirable to keep the use rate at about half of that to help ensure that EV drivers will not find all stations at a site in use, then a charging network would start to seem full to EV drivers when at 25% average daily use rate.

11.1.1 ChargePoint Network Capacity

If we assume ChargePoint's 10% offline station rate is evenly distributed through the useful charging hours of the day, this reduces our capacity target to 20%. The ChargePoint network has an overall average use rate of about 5%. That would suggest a capability of supporting charging for a fourfold increase in the number of electric vehicles in the regions covered by the ChargePoint network. Switching high-demand free stations to paid would be expected to lower demand by a factor of 4, which would therefore increase the

potential of the ChargePoint network to 16 times the current EV population.

11.1.2 Blink Network Capacity

Applying the same logic to the Blink Network, starting with a target of 25% average use rate, reduce that by the Blink Network's apparent offline station rate of 25% (pro-rated to 12.5% for the assumed 50% of the day that's available for public charging) to get a revised target of 12.5%. With the Blink Network's apparent average use rate at 3%, this suggests support for a fourfold increase in EVs.

Currently, all Blink stations provide free charging. They are expected to switch to paid charging this spring. Continued study will show how this affects demand and will thus obtain a better estimate of total EV support capacity.

11.1.3 Growing the Networks

Presumably, the charging network doesn't have to double in size to double the number of EVs supported. One would expect that the most popular stations will drive expansion at those sites while other less-used sites will not need to grow. This is another topic for future study.

11.2 Site Design Concerns

Best billing practices is an important topic with no clear answers. ChargePoint allows site owners to choose how their stations bill users, so there is flexibility for owners to experiment and evolve as needed. Blink takes a more uniform approach, which gives less control to site owners but more consistency for drivers.

Parking policy and appropriate signage is an area where site owners can benefit from the existing body of knowledge on how to make sites work.

Finally, accessibility for disabled persons is an issue that is receiving attention and should become clearer soon.

Acknowledgments

The author is grateful to the many volunteers who helped collect data for the site survey and to the following map vendors for their assistance:
Recargo, Inc. www.recargo.com
Open Charge Map, openchargemap.org

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Author

Tom Saxton has BA degrees in math and physics (University of Utah, 1983) and an MA in math (University of Utah, 1985). A computer programmer by trade, he worked on Microsoft Word for 10 years. He has been driving electric and documenting his experiences since 2008. He joined the Plug In America board of directors in January, 2011, and is currently serving as vice president. When not busy with electric cars, he can be seen volunteering as a referee at FIRST robotics competitions.