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EV Charging Infrastructure Roadmap

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Idaho National Laboratory

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ABSTRACT

As highlighted in the U.S. Department of Energy's EV Everywhere Grand Challenge, vehicle technology is advancing toward an objective to "… produce plug-in electric vehicles that are as affordable and convenient for the average American family as today's gasoline-powered vehicles …" [1] by developing more efficient drivetrains, greater battery energy storage per dollar, and lighter-weight vehicle components and construction. With this technology advancement and improved vehicle performance, the objective for charging infrastructure is to promote vehicle adoption and maximize the number of electric miles driven.

The EV Everywhere Charging Infrastructure Roadmap (hereafter referred to as Roadmap) looks forward and assumes that the technical challenges and vehicle performance improvements set forth in the EV Everywhere Grand Challenge will be met. The Roadmap identifies and prioritizes deployment of charging infrastructure in support of this charging infrastructure objective for the EV Everywhere Grand Challenge.

The Roadmap leverages experience of the authors, electric vehicle industry experts, and analysis of the extensive data collected by the U.S. Department of Energy from The EV Project and other infrastructure studies to identify priorities for deployment of plug-in electric vehicle charging infrastructure. This Roadmap utilizes these resources to identify the what, where, and when for future charging infrastructure deployment and the means of maximizing use of that charging infrastructure and increasing the use of existing charging infrastructure. The Roadmap also examines obstacles to deployment of future charging infrastructure and to use of existing charging infrastructure and recommends means by which these obstacles can be and are being overcome.

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FIGURES

ACRONYMS

AC	alternating current
ADA	Americans with Disabilities Act
AEV	all electric vehicle
DC	direct current
DCFC	direct current fast charger
DOE	U.S. Department of Energy
EVSE	electric vehicle supply equipment
EVSP	electric vehicle service provide
ETEC	Electric Transportation Engineering Corporation
INL	Idaho National Laboratory
OEM	original equipment manufacturer
PEV	plug-in electric vehicle

EV Charging Infrastructure Roadmap

1. INTRODUCTION

In March 2012, President Obama announced the EV Everywhere Grand Challenge to produce plug-in electric vehicles (PEVs) by 2022 that are as affordable and convenient for the American family as gasoline-powered vehicles [1]. The U.S. Department of Energy's (DOE's) Energy Efficiency and Renewable Energy team subsequently issued a framing document [1] to facilitate discussion among the public and participants in the EV Everywhere Grand Challenge workshops. A subsequent blueprint [2] provided an outline for DOE's technical and deployment goals for PEVs over the next 5 years. The blueprint identified technical targets for batteries, electric drive systems, vehicle light-weighting, climate control efficiency, and charging infrastructure.

This EV Charging Infrastructure Roadmap (hereafter referred to as Roadmap) is intended to utilize the experience gained from initial deployment and use of charging infrastructure. This includes DOE's own investment in charging infrastructure development and data collection through The EV Project and other charging infrastructure deployment projects to identify and prioritize EV charging infrastructure actions that provide the greatest support to EV Everywhere objectives for charging infrastructure, which includes the following

- Promote PEV adoption
- Increase electric miles driven
- Maintain electric grid reliability.

This Roadmap exclusively focuses on charging infrastructure required to support overall charging infrastructure objectives of the EV Everywhere Grand Challenge. It assumes that the vehicle, drive system, battery, and vehicle weight challenges set out in the EV Everywhere Grand Challenge are being achieved by separate efforts and activities. This means it focuses on **what** charging infrastructure should be installed, **where** it should be installed, and **when** it should be installed. The Roadmap focuses on and prioritizes the type, location, and uses of charging infrastructure that promote PEV adoption and increase electric miles driven.

2. METHODOLOGY

In its various papers, DOE's EV Everywhere Grand Challenge identified the technical targets that, if achieved, would enable PEVs to meet the overall objective of creating affordable convenient electric transportation for American families. The key roles that charging infrastructure plays in the EV Everywhere Grand Challenge are to promote PEV adoption and enable electric miles driven. This Roadmap provides the **what**, **where,** and **when** to guide electric vehicle service providers (EVSPs), governments, and electric utilities in fulfilling those roles. It provides guidance on **what** type of charging infrastructure should receive priority for deployment, **where** it should be deployed, and, based on a maturing electric vehicle market, it prioritizes **when** each of these charger types should be deployed.

This Roadmap follows studies conducted by DOE and others, including The EV Project. The EV Project is the largest deployment and study of PEV charging infrastructure ever undertaken to date. Other efforts by DOE's Vehicle Technologies Office that provided background information on use and/or deployment of charging infrastructure for the Roadmap include the following:

- ChargePoint America
- Chevrolet Volt – Demonstration fleet
- Chrysler PEV Ram Pickup – Demonstration fleet
- DOE's Grid Tech Team

- South Coast Air Quality Management District/Electric Power Research Institute/Via Motors
- Wireless Charging
- West Coast Electric Highway.

Data from The EV Project and these other DOE-supported infrastructure studies were the subject of an all-encompassing summary report titled, "Plug-in Electric Vehicle and Infrastructure Analysis," that was prepared by Idaho National Laboratory (INL) [3]. The information from that report was extensively used to establish this Roadmap's priorities.

The Roadmap also utilized the experience the authors gained from designing and conducting The EV Project and from their experience during the late 20th century when deploying charging infrastructure in support of original equipment manufacturers (OEMs) and converter PEVs. Additionally, the Roadmap includes input from leading PEV industry participants, discussions with key DOE Vehicle Technologies Office personnel, and analysis of charging infrastructure data collected and analyzed by INL's Energy Storage and Transportation Systems Vehicle and Infrastructure Testing and Research team.

The authors gained experience with charging infrastructure for a wide variety of PEVs through work conducted at the Electric Transportation Engineering Corporation (ETEC), which provided charging infrastructure for both on-road and industrial PEVs for over three decades. The following projects conducted at ETEC were related to electric transportation:

- Industrial charger design, installation, and operation
- On-road vehicle charger development, sales, support, and deployment
- Traction battery testing
- Electric vehicle racing, including vehicle design
- Various projects associated with safety, standards development, and other electric vehicle industry support.

A complete list of the early electric vehicle-era projects conducted by ETEC and a brief description of the projects can be found in Appendix C.

The most recent ETEC experience focused on defining, organizing, managing, and conducting The EV Project. In addition to experience gained by designing, manufacturing, and installing over 12,000 alternating current (AC) Level 2 chargers and 100 direct current (DC) fast chargers nationwide, The EV Project explored the business of providing and operating charging infrastructure. Most importantly, The EV Project collected an extensive amount of data from both the participating chargers and vehicles. These data were curated at INL and they provided a rich source of information for development of the Roadmap. This information is summarized in several lessons learned papers that have been published by the Energy Storage and Transportation Systems team at INL [4].

In addition to the experience and available data used as a foundation for the Roadmap, the experience of PEV industry experts was gathered by way of a request for input from vehicle OEMs, electric utilities, EVSPs, government, and PEV enthusiasts. The request contained a series of questions designed to query the representatives' experience and their opinions. A list of the questions asked and a summary of the responses can be found in Appendix A.

3. BACKGROUND

In order to frame the Roadmap, it was necessary to define the terms and terminology used in the Roadmap. Because the Roadmap is prepared in support of the EV Everywhere framing document and blueprint, many of the definitions used for the Roadmap are taken from these documents.

3.1 Vehicles

Although the Roadmap focuses on PEV charging infrastructure, the vehicles being charged are not all the same and, consequently, their charging needs also differ. Battery size, capability to fast charge, and use of a range extender all impact the vehicle's use and its charging options. The EV Everywhere Grand Challenge documents identified the following three different plug-in vehicle categories:

- PEV-40 – Plug-in hybrid electric vehicle with an all-electric range of about 40 miles
- AEV-100 – All-electric vehicle (AEV) with a range of about 100 miles
- AEV-300 – All-electric vehicle with a range approaching 300 miles.

3.2 Charging Infrastructure (What Charging Infrastructure is Installed)

The Roadmap classifies charging infrastructure by two characteristics: (1) charging station type and (2) charging station location. The types of chargers are precisely defined by the Society of Automotive Engineers in their standard J-1772 [5]. For use in this Roadmap, the exact definitions created by the Society of Automotive Engineers have been aggregated into the following three charging infrastructure types (referred to as the **what** of charging infrastructure):

- AC Level 1 – typically with a charge rate below 2.0 kW
- AC Level 2 – typically with charge rates between 3.0 and 10.0 kW
- DC fast charger (DCFC) – typically with charge rates between 20 and 120 kW.

These definitions are intended to reflect a clear differentiation between charging power levels that are currently deployed or have been developed and are ready for deployment. There has been some discussion in the industry regarding charging infrastructure that could charge light-duty PEVs at up to 350 kW [6]. However, this equipment is not currently deployed nor is its deployment imminent. Most charging stations deployed today as AC Level 1 are 16 amperes continuous (i.e., 1.7 kW); as AC Level 2 are 16 or 32 amperes continuous at 230 V (3.3 to 6.6 kW); or as DCFC typically have a maximum charging rate of 25, 40, or 50 kW. Although this Roadmap does not address Tesla's exclusive charging stations, Tesla also has a clear differentiation in power with their AC Level 2 stations and their DC "Superchargers" that have a charging rate of up to 120 kW and are the highest power charging stations in use today for light-duty vehicles.

3.3 Charging Infrastructure (Where Charging Infrastructure is Installed)

Another definition used in the Roadmap's classification of charging infrastructure involves location of charging stations (herein referred to as the **where** of charging infrastructure) and includes the following:

- **Residential** – charging infrastructure located at a parking location facilitating overnight charging (AC Level 1 or AC Level 2) and also known as at-home charging
- **Workplace** – away-from-home charging infrastructure located at business locations that is intended for exclusive use by employees of the business (in some cases, visitors) (AC Level 1 or AC Level 2)
- **Publicly Accessible** – away-from-home charging that is convenient to travel destinations and activities other than work and is available for use by any PEV (AC Level 2)
- **Intra-urban fast charging** – fast charging infrastructure at convenient locations within an urban area (DCFC)

- **Inter-urban fast charging** – fast charging infrastructure located between urban centers (DCFC).

The **where** of charging infrastructure in the context of this Roadmap connotes a specific purpose for charging units rather than the venue type:

- A **residential charging station** is intended to provide an overnight charge. These chargers are typically owned by the PEV driver and installed at a location controlled by the PEV driver.
- A **workplace charging station** provides access to charging while a PEV is parked at the driver's work location. These chargers are typically provided by the business for the benefit of the employees.
- A **publicly accessible charging station** provides access to charging for any PEV and is intended to be an opportunity charger. Therefore, it is located at an accessible location that is typically associated with some activity that will occupy the PEV driver for an hour or more. This differs from the workplace charging station, which is normally restricted to employees of a particular company.
- An **intra-urban DCFC** is intended to provide range extension for additional electric miles to be driven within a metropolitan area. These chargers are often located at convenient stopping points and are often along urban freeways and other heavily traveled streets. A prominent use of intra-urban DCFC charging is often times as a "top up" charge, enabling the PEV driver to extend their day's activities within the urban area before returning to their home charging location. These intra-urban DCFC stations may also be used in place of an overnight charging site (i.e., virtual residential) by those PEV drivers living in multi-unit dwellings, who do not have reliable access to an overnight parking/charging spot.
- An **inter-urban DCFC** is intended to facilitate travel between metropolitan areas and are located along highways between urban centers. By way of example, Tesla has developed its Supercharge network that is predominately along travel corridors between metropolitan areas (Figure 1). The Tesla network has been fully developed to support inter-urban travel for the AEV-300 Tesla vehicles.

Figure 1. Map of Tesla's North American Supercharger network (image courtesy of Teslamotors.com).

3.4 Market Maturation (When Charging Infrastructure is Installed)

The final aspect of the Roadmap defines the following phases (the **when**) that each maturing PEV market goes through:

- Early Stage – PEV adoption by innovators and early adopters who are satisfied that the vehicle range can meet their daily transportation needs using only residential charging overnight. There is little away-from-home (e.g., publicly accessible, workplace, intra-urban, and inter-urban fast charging) infrastructure in place. Adoption and use of PEVs are not dependent on away-from-home charging.
- Transition – The number of PEVs in the local market increases, as well as the density of deployed away-from-home charging infrastructure. Utilization of away-from-home charging increases as PEV drivers become familiar with the location and use of away-from-home charging infrastructure, allowing them to expand the use of their vehicles and increase their electric miles driven. With use of workplace and intra-urban DCFC away-from-home charging, the early majority adopters become more confident that an AEV-100 can meet their daily transportation needs and begin to purchase more AEV-100 vehicles.
- Mature – Pervasive away-from- home charging infrastructure exists. Increased availability and use of away-from home charging infrastructure allows the all-electric range of vehicles to be extended beyond that provided by an overnight charge at their residential charging infrastructure, resulting in an increase in electric miles driven. Increased vehicle capabilities, specifically the availability of a competitively priced AEV-300, have many late majority PEV purchasers selecting AEV-300s. These AEV-300 drivers meet their charging needs predominately with at-home charging and with range extension for travel within a metropolitan area provided by workplace charging and intra-urban fast charging, and for travel between metropolitan areas provided by inter-urban DCFC.

3.5 Current Plug-In Electric Vehicle Industry Status

The current status of the PEV market and the charging infrastructure to support this market has been well reported by DOE’s Office of Energy Efficiency and Renewable Energy through the data collection and analysis efforts of INL and the Alternative Fuel Data Center. According to these sources [7] (at the end of the first quarter of 2016), there are approximately 32,750 PEV charging outlets (i.e., AC Level 1, AC Level 2, and DCFC) available for public use at 13,750 stations. Additionally, there are another 5,118 charging outlets at approximately 2,430 stations for private use (i.e., workplace and fleet). The 276 Tesla stations shown in Figure 3 and their associated charge outlets are contained within these totals.

According to *Inside EVs* [8], 438,298 PEVs have been sold from December 2010 through the first quarter of 2016. Distribution of PEV sales by the vehicle categories defined in Section 3.1 is shown in Figure 2. Although PEV sales are growing, they still only represent 0.02% of the 250 million vehicles registered in the US. There are markets where PEV sale represent 3% of new sales, but charging infrastructure for such a small fraction of the vehicle population faces a significant challenge to claim a piece of public parking space.

One of the more important aspects of the Roadmap is that it applies to local market conditions, which vary significantly in their adoption of PEVs. The current status of each market may vary based on local factors, including the following:

- Climate (cold weather climate versus warmer or milder climate)
- Local incentives to purchase PEVs and/or install charging infrastructure
- Demographics (most PEVs are not yet comparably priced with gasoline vehicles)
- Presence of innovators and early adopters to start the market.

For this reason, Roadmap recommendations are segregated by market maturity and are intended to be applied to markets based on their specific level of PEV adoption.

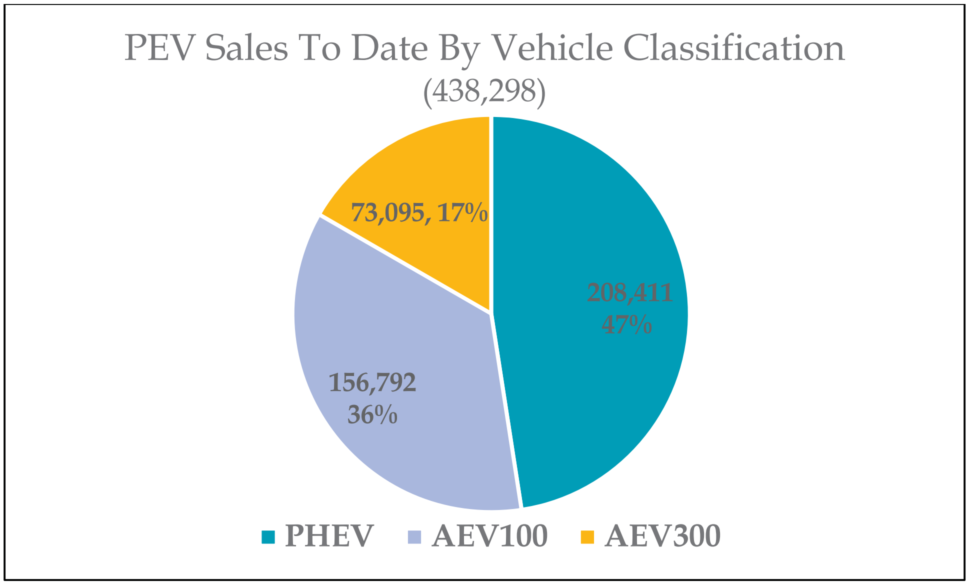


Figure 2. PEV sales from December 2010 through the first quarter of 2016.

3.6 Input from Electric Vehicle Industry Experts

Industry experts were asked about their views regarding deployment and use of residential and away-from-home charging and their views on some of the ways for overcoming obstacles to deployment and use that have been implemented. The questions asked and an analysis of the answers provided are included in Appendix A, with key results summarized as follows:

- Workplace charging was overwhelmingly considered the most effective away-from-home charging method to promote both PEV adoption and electric miles driven. In fact, one respondent commented that workplace charging was "…THE biggest factor in PEV adoption…"
- Cost of the electric vehicle supply equipment (EVSE) and its installation were considered the most critical obstacle to deployment of residential charging infrastructure. The next most important factor was the company standing behind the EVSE.
- When asked to select who was best suited to deploy and operate charging infrastructure, three times as many of the industry experts felt that electric utilities were better suited than for-profit companies or any other entity.
- When asked about the different travel needs met by PEVs and the relative importance of away-from-home charging stations, electric vehicle industry experts stated that commuting benefited the least from it. While, not surprisingly, away-from-home charging was considered critically important for inter-urban travel.
- Industry experts were asked for their input regarding tax incentives as a way of overcoming the cost obstacles to deployment. Tax incentives for home charging installation were considered helpful, but not critical for promoting PEV adoption. However, tax incentives were considered three times more critical for away-from-home charging.
- One observation made by a number of respondents had to do with the "unintended consequences" that free charging programs have on use of away-from-home charging stations. The concern they

expressed was that free away-from-home charging would lead to overcrowding at some stations and could have a negative impact on PEV adoption.

- Another observation made by more than one expert highlighted the benefit to PEV drivers, station hosts, and EVSPs that comes from greater use of DCFC stations. Demand charges become less per charge with more use and, with sufficient use, would become negligible.
- 93% of the respondents feel that smart charging, which includes management of away-from-home charging infrastructure by utilities and/or hosts, is important or critically important for grid management.
- 75% of respondents thought that "free to charge" programs promoted PEV adoption, but only 50% thought that it encouraged use of away-from-home charging; therefore, it increased electric miles driven.

Companies represented by industry experts providing input are listed in Appendix B. This was assimilated with data and experience from current charging infrastructure installation and operation to develop recommendations regarding the priorities for the **what**, **when,** and **where** of future charging infrastructure deployment.

4. THE ROADMAP

EV Everywhere literature states that the availability of publicly accessible charging infrastructure promotes PEV adoption by increasing PEV driver confidence and alleviating "range anxiety." Of course, use of publicly accessible infrastructure will also enable more electric miles to be driven. This is especially true for plug-in hybrid electric vehicles, which can extend their electric vehicle miles driven before engaging their onboard internal combustion engine. The charging infrastructure Roadmap expands on the EV Everywhere Grand Challenge framing document and blueprint by identifying and prioritizing the **what**, **where,** and **when** that charging infrastructure could fulfill its role in the EV Everywhere Grand Challenge of promoting PEV adoption and increasing electric miles driven.

The Roadmap was developed within the framework established by the EV Everywhere Grand Challenge and the definitions cited above. Within this framework, the Roadmap utilizes information derived from data collected and analyzed for The EV Project and other infrastructure studies, along with the authors' first-hand experience of deployment and early operation of PEV charging stations. To be effective and useful, the Roadmap drew upon these data and experience to determine how the PEV charging infrastructure could meet its objectives, including promoting PEV adoption and increasing electric miles driven. It was concluded that to meet these objectives, existing PEV charging infrastructure must be used more and future charging infrastructure deployed must be prioritized to meet the needs of the changing/maturing PEV market, thereby both encouraging PEV adoption and maximizing use (i.e., electric miles driven) of these PEVs. These conclusions are supported by analysis of data collected in DOE infrastructure studies that show vehicles charged away from home between 30 and 60% of the time, which supplemented their home charging with an away-from-home charge (i.e., workplace charging and/or publicly accessible charging) about every other day [3]. These vehicles averaged 1.5 total charging events per day driven. This frequent charging enabled these vehicles to average 43 miles per day, which is 72% farther than the average daily travel for those that never charged away from home [9].

The Roadmap not only addresses the priorities for future charging infrastructure deployment, but also identifies obstacles for deployment and use of existing charging infrastructure. These two subjects are addressed separately. The priorities for deployment of future charging infrastructure are presented first, followed by a discussion on obstacles to deployment of future charging infrastructure, use of both future and existing charging infrastructure, and ways that these obstacles can be overcome.

By mapping deployment of future charging infrastructure, the authors examined the relationships that exist between PEV classifications and charging infrastructure types and between charging infrastructure locations and the maturing PEV market. This approach maps the **what**, **where,** and **when** for deployment of charging infrastructure based on the local state of the PEV market maturity. It identifies **what** charger type best supports a particular PEV classification, **where** these are most effectively deployed, and **when** this deployment would best support the market being mapped. The result of this approach is represented by the matrix shown in Figure 3.

Phase	PEV-40	AEV-100	AEV-300
Early Stage	**Residential AC Level 1**	**Residential AC Level 2**	**Residential AC Level 2**
Transitional	**Workplace AC Level 2**	**Workplace AC Level 2**	**Intra-Urban DC Fast Charger**
Mature	**Publicly Accessible AC Level 2**	**Intra-Urban DC Fast Charger**	**Inter-Urban DC Fast Charger**

Figure 3. PEV charging infrastructure Roadmap matrix.

4.1 Key Assertions

This Roadmap matrix is based on a few key assertions about PEV use and charging infrastructure availability.

4.1.1 Charging At Home

Fueling a PEV presents a new paradigm for the vehicle owner. Conditioned to take their vehicle to a fueling station, there is a tendency to apply that same paradigm to fueling an electric vehicle. However, the "give me at least 300 miles of range and let me refuel quickly on the road" view of fueling need not be the paradigm for a PEV. The ability to conveniently and cost-effectively dispense fuel at home is a paradigm shift that applies to all PEVs at all stages of charging infrastructure development. Two factors are key to this paradigm shift. First, home (or any place that the vehicle is parked overnight) is the location that a PEV spends the greatest number of hours. Therefore, it is the most logical location for charging the PEV. Second, the time available for charging the PEV at home far exceeds that required to return the energy "typically" used on daily PEV operation. AC Level 2 charging provides up to 6.6 kW for charging. Data from The EV Project showed that PEVs in the project spend 40% of their time connected to the charger, but only 8% of the time actually charging [10]. With even 5 hours of charge time, over 33 kWh can be returned to the PEV. At a conservative 3 miles/kWh, this represents 100 miles of driving returned to the PEV, overnight, without need of going to a fueling station. Adoption of this overnight PEV fueling paradigm is rapid with PEV owners, which is evidenced by data from the EV Project, where 85% of all charging took place at home [9].

In addition to the convenience of not having to go to a fueling station, residential electric rates are nearly always lower than commercial rates paid for charging energy in public locations. Further, time-of-use rates are often available at residential locations, making charging off peak (i.e., at night when a PEV typically charges) the lowest cost electricity of any location and time.

Overnight home charging has the added benefit of minimizing impact on the electric grid from PEV charging, because charging occurs at a time when demand from other electricity uses is at a minimum. This allows energy production from the lowest-cost generation source, without the need for additional facilities to handle increased power requirements.

4.1.2 Charging At Work

Time spent at work represents the second longest time available to charge a PEV. Workplace charging provides an opportunity to extend PEV range by benefitting those owners living farther from work than can be driven round trip on a single charge. It can also provide additional flexibility for the PEV driver by extending their day's travel beyond the range of their overnight charge. This range extension is evident in data from The EV Project when drivers charged their PEVs at their workplace and their electric miles travelled increased by 15% [11]. Additionally, EV Project data showed that 22% of the time the drivers charged at work because this charging was necessary to meet their day's driving requirements [4]. This increase in electric miles driven also allows PEVs to meet the trip requirements of more drivers, which encourages PEV adoption.

The energy needed to meet nearly all PEV electric miles driven can be provided by a combination of home and workplace charging. This is evidenced by data from The EV Project where, when workplace charging was available to the PEV driver, 98% of all charging took place at home or at work (only 2% elsewhere) [1].

4.1.3 Daily Trip Distance

For development of this Roadmap, it is assumed that purchasers of the 1 million PEVs targeted by the EV Everywhere Grand Challenge will drive PEVs as part of their daily routine, which means their trips and trip distances will be typical of those taken prior to purchasing a PEV and will not be more and/or longer just because they are being performed with a PEV. For this reason, the average vehicle mile traveled for the United States provides a reasonable measure of the average charge energy required to support a PEV. In 2009 (i.e., the most recent year of this survey, with the next survey underway and due for publication in 2017), the average daily vehicle miles traveled was 28.97 (Figure 4) [13]. Only 5.1% of trips taken were greater than 30 miles in length (Figure 5). These data indicate that nearly 95% of the trips taken on a daily basis can be fueled by charging overnight at home. Even more of these trips can be fueled by also charging at work. Therefore, for this Roadmap, it is assumed that over 95% of electric vehicle home and/or workplace charging will fuel the miles driven.

Table 3. Summary of Travel Statistics
1969, 1977, 1983, 1990, and 1995 NPTS, and 2001 and 2009 NHTS.

	1969	1977	1983	1990	1995	2001	2009	95% CI
Per Person								
Daily Person Trips	2.02	2.92	2.89	3.76	4.30	3.74	3.79	0.03
Daily PMT	19.51	25.95	25.05	34.91	38.67	36.89	36.13	1.35
Per Driver								
Daily Vehicle Trips	2.32	2.34	2.36	3.26	3.57	3.35	3.02	0.03
Daily VMT	20.64	19.49	18.68	28.49	32.14	32.73	28.97	0.71
Per Household								
Daily Person Trips	6.36	7.69	7.20	8.94	10.49	9.66	9.50	0.09
Daily PMT	61.55	68.27	62.47	83.06	94.41	95.24	90.42	3.38
Daily Vehicle Trips	3.83	3.95	4.07	5.69	6.36	5.95	5.66	0.06
Daily VMT	34.01	32.97	32.16	49.76	57.25	58.05	54.38	1.34
Per Trip								
Average person trip length (miles)	9.67	8.87	8.68	9.47	9.13	10.04	9.75	0.36
Average vehicle trip length (miles)	8.89	8.34	7.90	8.85	9.06	9.87	9.72	0.22

Note:
- Average trip length is calculated using only those records with trip mileage information present.
- 1990 person and vehicle trips were adjusted to account for survey collection method changes (see 2001 Summary of Travel Trends Appendix 2).
- PMT is Person Miles of Travel. VMT is Vehicle Miles of Travel. CI is Confidence Interval. NPTS is Nationwide Personal Transportation Survey.

Figure 4. Travel statistics from the 2009 National Household Travel Survey.

2009 NHTS
Vehicle Trips (Travel Day VT, annualized)
Number of Vehicle Trips (VT) by Trip Distance (TRPMILES) Including Trips 2 Miles or Less
Where TRPMILES GE 0

Calculated Trip distance converted into miles	Travel Day Vehicle Trips		
	Sample Size	Sum (Millions)	Percent
Less than 0.5 miles	28,892	9,191	4.0
1 mile	116,184	37,205	16.1
2 miles	97,869	29,803	12.9
3 miles	78,713	23,296	10.1
4 miles	56,824	16,686	7.2
5 miles	55,197	16,830	7.3
6 - 10 miles	141,966	43,040	18.6
11 - 15 miles	63,652	20,420	8.8
16 - 20 miles	33,824	11,329	4.9
21 - 30 miles	32,844	11,443	5.0
31 miles or more	35,208	11,740	5.1
All	741,173	230,982	100.0

Source: Federal Highway Administration, 2009 National Household Travel Survey (NHTS)
Tabulation created on the NHTS website at http://nhts.ornl.gov

Figure 5. Vehicle trips data from the 2009 National Household Travel Survey.

4.2 Matrix

The Roadmap matrix presents infrastructure and deployment priorities (i.e., what and where) for each vehicle type at each stage of infrastructure maturity (i.e., when). It is not intended to dismiss the benefit of having additional charging infrastructure types available at other locations during any phase of infrastructure maturity. Rather, it is intended to identify the most important type and location for charging infrastructure to support PEV adoption and increase electric miles driven.

The PEV classifications shown in the top row of the matrix in Figure 5 represent three classifications defined in the EV Everywhere framing document and reflect a maturation of PEV technology. As the technical objectives detailed in the EV Everywhere Grand Challenge are achieved, the improved efficiency and lower component costs enable widespread availability of affordable AEV-300 vehicles. (Note: Although AEV-300 vehicles are currently available, they do not meet the EV Everywhere objective of affordability; "… to produce plug-in electric vehicles (PEVs) that are as affordable and convenient for the average American family as today's gasoline-powered vehicles" [1]).

As the market matures from early stage and transitions to mature stage (when), the priority of the infrastructure types (what) and locations (where) change to support the maturing market. The following subsections of the Roadmap examine charging infrastructure deployment priorities for each vehicle classification as the market matures.

The contents of the Roadmap matrix are described by examining maturation of the charging infrastructure (i.e., rows) that supports each of the vehicle classifications (i.e., columns) defined above.

4.2.1 PEV-40

During the early stage, charging infrastructure needed to support PEV-40 use is merely the residential infrastructure provided at the time of vehicle purchase. During this early stage, the PEV-40 is typically purchased by drivers who are likely concerned with electric range and that concern is addressed through use of the vehicle's onboard range extender (internal combustion engine). Therefore, during the early stage, the PEV-40 choice ignores any away-from-home charging and places the highest priority on facilitating rapid and cost-effective installation of residential charging infrastructure.

As market and PEV-40 drivers mature from early stage to transition, drivers demonstrate an increasing desire to drive in electric mode only (aka "gas anxiety"). During the EV Project, Volt drivers charged 36% more often than Leaf drivers on days the vehicle was driven [3]. It was demonstrated during The EV Project that the most effective way to support PEV adoption and increase electric miles driven is through workplace charging. For Volt drivers in the EV Project, 87% of their charging was done at home [9]. Of the remaining 13% (which were away-from-home), 92% of the charging events were conducted at the workplace if the Volt driver had access to workplace charging [9]. In fact, of those Volt drivers with access to workplace charging, 98% of all of their charging was done at home or at the workplace [9]. Therefore, the highest priority for charging infrastructure deployment in the transition stage of maturity is for workplace charging.

During the mature market phase, electric miles driven for PEV-40 vehicles are maximized by using publicly accessible AC Level 1 and AC Level 2 charge stations. These charge stations must be located at venues that are frequented by or attract PEV drivers, because they are typically used as an "opportunity" charge. In this case, the purpose of a trip is to reach a destination. If that destination also has a charge station, the PEV driver may take the "opportunity" to charge. The actual frequency of opportunity charging is strongly dependent on the cost to charge, because it competes with the cost to charge at home. Therefore, as the local vehicle market reaches the mature phase, an emphasis on deployment of cost-competitive publicly accessible charging infrastructure is appropriate. At this time, the maturity of many local markets is not sufficient to know where the most "attractive" charging locations might be. Recommendations of specific venues for charging infrastructure deployment is not the purpose of the

Roadmap; this has been reported in a number of lessons learned papers produced from The EV Project [14].

4.2.2 AEV-100

Evaluation of AEV-100 charging infrastructure use in early stage maturity shows that similar to infrastructure early stage utilization by PEV-40s, AEV-100 drivers also overwhelmingly prefer to charge at home. During the EV Project, 84% of Leaf (i.e., AEV-100) charging was done at home, while 87% of Volt (i.e., PEV-40) charging was done at home [9]. This was in an environment where publicly accessible charging was available in significant quantities in metropolitan areas where the EV Project was conducted. The author concluded that the preference for residential charging results from the fact that many early stage PEV purchasers buy their vehicle anticipating it will satisfy a very high percentage of their daily trip needs with use of residential charging. Based on this preference for convenient residential charging, the priority for AEV-100 charging infrastructure in the early stage of vehicle market maturity is to facilitate installation of residential charging infrastructure.

Charging infrastructure priorities during the transition phase of market maturity for AEV-100 vehicles also mimic those for PEV-40s. When workplace charging was available to support residential charging, this combination provided 98% of all charging needs for EV Project participants driving Nissan Leafs (i.e., AEV-100) [9]. It is anticipated that use of publicly accessible charging infrastructure by AEV-100 vehicles will only make a marginal contribution to electric vehicle miles driven, but will have a positive impact on vehicle adoption because potential PEV purchasers will see infrastructure being used to support electric transportation. Therefore, the priority for AEV-100 charging infrastructure during the transition stage of vehicle market maturity is for workplace charging.

Unlike PEV-40s, the AEV-100 vehicles have the ability to charge quickly with DCFC. Similar to workplace charging, this enables the AEV-100 vehicles in a mature market to restore transportation flexibility and increase their electric miles driven. Leaf vehicles in the EV Project that charged away from home at DCFCs tended to do so at the end of the work day (i.e., between 4 and 7 p.m.) (Figure 6) and along commuter routes in urban areas. This indicates utilization of away-from-home charging that extends the day's activities before returning home. Therefore, as the vehicle market progresses to the mature stage, the priority for AEV-100 charging infrastructure should include intra-urban DCFC.

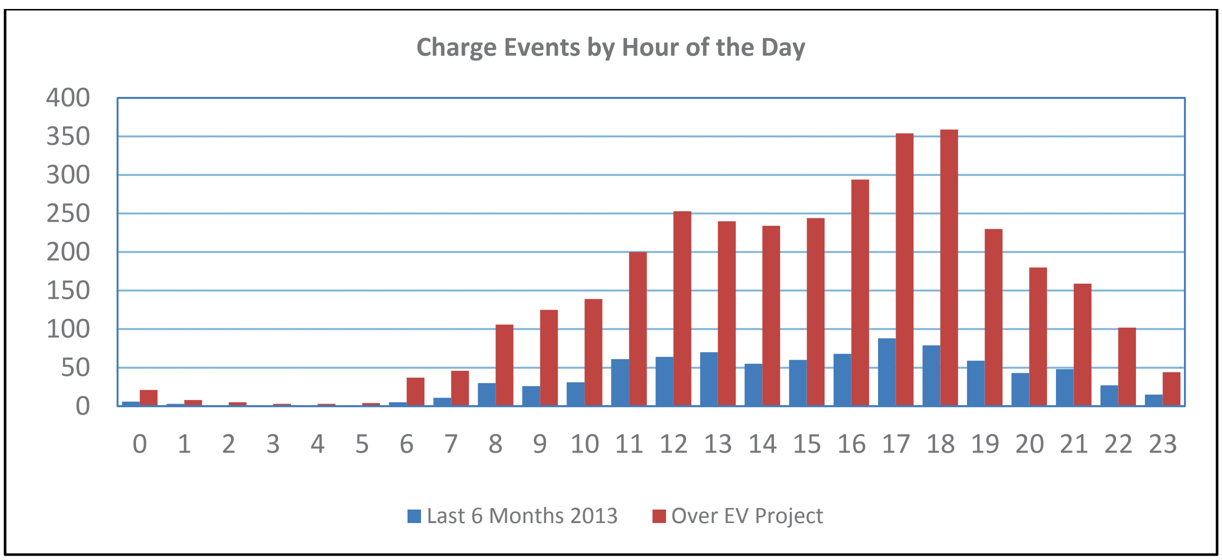


Figure 6. Hour of the day when popular DCFCs were used [19].

4.2.3 AEV-300

Roadmap projections on charging infrastructure needs for AEV-300 vehicles are based on a combination of the vehicle's capabilities related to AEV-100, capabilities of AEV-300 compared to typical American vehicle transportation use, and from industry observations on the most prevalent AEV-300 vehicle currently in the market today (i.e., the Tesla Model S).

Sufficient data are not available for vehicles currently on the road to directly compare AEV-300 vehicle use or charging patterns to AEV-100 vehicles. However, the range available and refueling technology employed can be used to reasonably extrapolate from AEV-100 charging patterns and typical gasoline vehicle use to identify the charging patterns expected for AEV-300 vehicles. It is important to recognize that when considering use of an AEV-300 vehicle, the 300-mile range envelopes nearly all of the daily trip needs for a typical U.S. driver. According to a study by the Earth and Environmental Engineering Department at Columbia University [15], which based many of their conclusions on National Highway Traffic Safety Administration data, the average trip distance for U.S. drivers is 5.95 miles and the daily average miles driven by urban drivers is 36.5. The study also concluded that about 95% of the daily miles driven are below 120 miles and 99% are below 250 miles. With the range of the AEV-300, the early stage of market maturity for drivers of these vehicles will be supported by residential charging infrastructure. Therefore, the priority for charging infrastructure support for early stage market deployment of AEV-300 vehicles is to facilitate residential charger installation, particularly higher power chargers that may be available to support the larger-capacity batteries in AEV-300 vehicles.

The greater range of an AEV-300 makes workplace charging used by PEV-40 and AEV-100 vehicles in the transition phase of market maturity less relevant. Rather, the ability to fast charge the AEV-300 using intra-urban DCFC will, during the transition phase of vehicle market maturity, provide the opportunity for range extension in unplanned instances when the start-of-the-day operating range is not sufficient. Therefore, during the transition phase of vehicle market maturity, the priority for AEV-300 charging infrastructure should be for intra-urban DCFC. It should be noted that this publicly accessible intra-urban DCFC infrastructure also supports increasing range and increase of electric miles driven for AEV-100 vehicles.

As the market moves to maturity and affordable AEV-300 vehicles become more widely available, there will be more PEV buyers who want to be able to make frequent travel between urban areas. With an extensive range and the availability of fast charging, inter-urban travel becomes a convenient reality in the mature market. Therefore, the priority for charging infrastructure deployment during the mature phase of AEV-300 market development is for inter-urban DCFC.

The concept of charging infrastructure to support AEV-300 inter-urban travel has been demonstrated effectively by Tesla through its SuperCharger deployment. As seen in Figure 1, Tesla has deployed a significant inter-urban DCFC network to support inter-urban travel of the Model S and future Tesla vehicles. This network is unique to Tesla vehicles (i.e., it uses a proprietary connector), is offered free to Tesla owners, and has a maximum charge power of 120 kW to shorten the charge times anticipated for inter-urban travel.

Tesla's Charging Infrastructure

Although it is not affordable to the "average American family," the only AEV-300 products currently available in the U.S. marketplace are the Tesla models (i.e., the Roadster, the Model S, and the Model X).

Tesla's charging infrastructure deployment strategy is similar to that being promoted in the EV Everywhere Charging Infrastructure Roadmap.

When first launched in 2011, Tesla vehicles had only at-home charging available. This was followed by deployment of publicly accessible stations in mid-2013. The first of these Tesla public stations were superchargers (i.e., DCFC), which were deployed along transportation corridors (i.e., inter-urban locations).

4.3 Charging Infrastructure

As discussed earlier, the Roadmap defines PEV charging infrastructure by hardware classification (i.e., rate of charge) and by the role the charging station fulfills (i.e., location type). The following discussion examines the roles the various charging infrastructure types and locations fulfill. It also identifies obstacles to both deployment and use of each type of charging infrastructure and suggests actions for overcoming these obstacles.

4.3.1 Residential Charging

Residential charging is by far the most frequently used location for charging. Its role is the primary and most convenient place to restore the PEV's flexibility as a means of personal transportation. This status as the most frequently used charging location is not affected by vehicle classification or maturity of market. Home charging is and will continue to be the predominant place to charge.

4.3.1.1 Obstacles to Deployment and Use. The obstacles to deployment of residential charging units lessen as a natural result of local and national market maturity. The primary obstacles to deployment have included EVSE cost, cost of installation, and cost and inconvenience of permitting. Since the beginning of the current generation of PEV charging hardware, the prices for home charging units have fallen. They have fallen from around $1,500 in 2011 to around $500 today. Most units today are fitted with plugs, making them much easier and more cost effective to install. Plugs fitted to charging units also allow a separation of the installation of the wall socket from the charging unit purchase. This allows the electrical infrastructure to be installed independent of vehicle and residential charger delivery and makes transfer of the residential charger easier in the event the PEV driver moves. Permitting authorities are also much more familiar with home charging stations today and more of them are simplifying the permitting process for home charging stations, including over-the-counter permits and online permitting.

4.3.1.2 Overcoming the Obstacles to Deployment and Use. One of the ways of reducing home charging installation costs would be by to require that all new homes be built PEV ready. This would be accomplished through installation of a dedicated circuit in the garage. Some permitting authorities have adopted this and some "suggest" it, but most still do not. The cost of including a dedicated circuit and "stub-out" for the outlet would be insignificant in the home's overall cost, but would be a significant cost saving for the homeowner and potential PEV adopter. This can be accomplished through a change to building codes and is currently being pursued by DOE's Vehicle Technologies Office through interface with the International Code Council.

Streamlining the permitting process provides another opportunity to facilitate residential charging infrastructure. During The EV Project, several progressive permitting authorities (i.e., authorities having jurisdiction) adopted online or self-inspection processes for permitting residential charger installations. The positive impact of these processes during The EV Project are documented in a lessons learned paper entitled, "What were the 'Best Practices' Identified for Residential Charger Installations?" published by the Energy Storage and Transportation Systems team at INL [16].

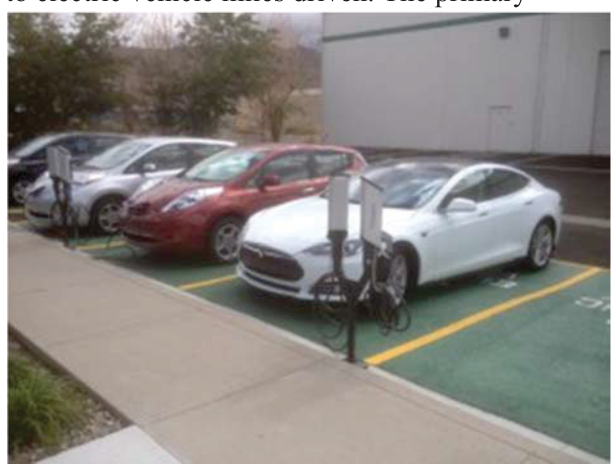
Use of residential charging can be encouraged and any potential negative impact from charging demand on the electric grid can be mitigated through implementation of time-of-use electric rates or special EV rates that offer low-cost, off-peak electric energy costs and no demand charge. Many electric utilities offer these rate incentives now. Their effectiveness was demonstrated during the EV Project by San Diego Gas and Electric's implementation of an experimental rate study to determine the impact of price incentives on residential charging behavior. The San Diego Gas and Electric rate study showed that the greater the differential electrical price between utility non-desired charge time and its desired charge time, the greater the behavioral change in driver residential charging [17].

4.3.2 Away-From-Home Charging

Away-from-home charging includes both workplace charging and publicly accessible charging stations, including AC Level 1, AC Level 2, and DCFC.

Workplace charging is similar to home charging, because when it is available to a PEV driver, it is extremely convenient. Also like home charging, it typically has a sufficient “connect time” to fully recharge the vehicle battery and restore full transportation flexibility to the PEV driver/owner.

Although there are a few DCFCs closely associated with employers and could be considered workplace chargers, most workplace chargers are either AC Level 1 or AC Level 2. This is usually the case because of the longer connect times available and the significantly lower cost for the chargers and their installation. Publicly accessible AC Level 2 stations are much more abundant than workplace charging stations, can be used by more PEV drivers, are typically used for shorter connect times, and are generally in a conspicuous location, thus promoting PEV adoption. However, utilization of publicly accessible AC Level 1 and AC Level 2 charging stations is quite low when compared to workplace charging stations. Although it depends on PEV to workplace station ratios, most workplace charging stations are used every day and contribute significantly to electric vehicle miles driven. The primary purpose for publicly available charging stations is to provide PEV drivers the opportunity to charge when it is convenient to their other activities. Because PEV drivers can meet the vast majority of their daily driving needs by charging at home, it is often not convenient to pay for charging away from home when it is not needed to complete their day’s activities.



4.3.2.1 Obstacles to Deployment and Use. Most of the obstacles to deployment of away-from-home AC Level 1 and AC Level 2 charging stations are the same, whether the station is for workplace use or is publicly accessible. However, the obstacles to utilization of the stations vary significantly between workplace and publicly accessible charging.

The primary obstacles to deployment for away-from-home charging stations are the same as they were for home charging units: unit cost, installation cost, and permitting cost and inconvenience. However, for away-from-home stations, there has not been the market-driven lessening of these costs that were described above for residential charging.

With their installation typically in a weather-exposed location, the away-from-home stations need to be more robustly constructed and often require networking for access control. They also cannot be more simply installed because electrical code requires the units be hard-wired (i.e., not outfitted with a plug).

One way that per charging port costs have been reduced for many away-from-home stations has been to make them "two-headed," providing two charging ports per charging pedestal. These are typically more expensive per pedestal, but less expensive per charging port. There has been some lowering of hardware costs for away-from-home chargers, but in the other two areas (i.e., installation cost and permitting cost), there has not been a reduction in cost and is not likely to be. These costs are driven by construction labor (i.e., electricians, masons, and machine operators) costs and commercial building permit costs, which do not benefit from increases in scale.

An important lesson learned about installation costs for away-from-home charging infrastructure from execution of the EV Project is that each installation site is a new construction project, with its own conditions, property owner requirements, site conditions, and available power. Additionally, requirements for accessibility as defined by the Americans with Disabilities Act (ADA) can have a significant impact on both hardware and installation costs in jurisdictions that define and enforce ADA requirements on PEV charging.

The obstacles to use of away-from-home AC Level 1 and AC Level 2 stations differs between workplace and publicly accessible stations, with more obstacles to use of publicly accessible AC Level 1 and AC Level 2 charging stations. Amongst the most prevalent obstacles to use of publicly accessible stations are public awareness, cost to charge, and a lack of "need" to charge away from home. Public awareness most often presents itself in the form of "ICE-ing" (i.e., internal combustion engine [ICE] vehicles, parking at charging locations that prevents access to the charging station).

The cost to charge is also an obstacle to use due to the need for most station owners to get a tangible return on their investment on the publicly accessible charging infrastructure, whether the station owner is an EVSP or site owner/host. This includes a return on the cost to purchase and install the charger and reimbursement for the cost of electricity and demand charges if any. Because commercial electric rates are typically more expensive than residential rates and publicly accessible charging typically occurs on-peak rather than off-peak, the cost of electricity is significantly greater for publicly accessible charging than for residential charging. Given this and with the majority of daily driving needs for PEV owners met with a single charge obtained at the overnight charging location, use of publicly accessible AC Level 2 charging is typically limited to extending vehicle range beyond what is available from a single overnight charge.

Pros and Cons of "Free Charge-to-Charge" Programs

There is little doubt that free charging offered by Tesla, Nissan, BMW, and others promotes PEV adoption. After all, who would not want to refuel for free? For those already considering the acquisition of a PEV, 2 years of free public charging just might be the closer.

In spite of low gasoline prices, sales of PEVs in 2016 are setting monthly sales records. Free charging might be part of the reason why.

However, as was pointed out by a number of PEV industry experts who provided input to the Roadmap, free charging has its downsides. Two issues have been identified that make this unlikely to be a long-term purchasing incentive proposition (1) overcrowding of some popular charging sites by "free chargers" will keep those who may need a charge to get home feeling like they have been "IC'ed" again and (2) free access to public charging is unlikely to have much impact on electric miles driven because many drivers are just getting the free electricity instead of paying at home.

There are few obstacles to use for workplace charging stations other than a mismatch between the number of users and stations. Many employers find that after they have installed stations for use by their employees, they soon do not have enough. There are many publications on how employers have implemented various station-sharing initiatives. Some can be found at the website for DOE's Workplace Charging Challenge [18].

4.3.2.2 Overcoming the Obstacles to Deployment and Use. As discussed above, many of the obstacles to deployment are financial costs, which are difficult to reduce for commercial installations. However, there are ways to overcome or reduce the obstacles to charging station use and deployment, including costs:

- Deployment
  - Have commercial building codes include a provision for dedicated circuits for charging stations
  - Add clarification to ADA parking requirements
  - Continue charging infrastructure investment tax credits.
- Use
  - Provide “no charge to charge” programs to encourage convenience charging at publicly accessible charging stations and familiarize PEV drivers with the location and use of this infrastructure
  - Continue support for Plugshare and other charger location applications
  - Continue to promote PEVs as a cleaner alternative for personal transportation
  - More vehicles create more demand for convenience charging at venues frequented by PEV drivers.

4.3.3 Direct Current Fast Charging

Publicly accessible DCFC presents a different use case for PEV drivers than publicly accessible AC Level 1 and AC Level 2. The latter are truly a convenience charge, whilst DCFC is more often a means to fulfilling a travel need. Additionally, DCFC only applies to the AEV-100 and AEV-300 vehicles, because PEV-40 vehicles in America do not have fast-charging capabilities. Data from DOE infrastructure studies indicate that either a charge is needed in order to get back to a long-term charging site (i.e., home or possibly workplace) or it is needed to extend the day’s activities. The latter condition can be seen in a number of the graphs that can be found in the lessons learned paper entitled, “What were the use patterns observed at the highly-utilized DC fast charge sites?” published by the Energy Storage and Transportation Systems team at INL [19]. Figure 6 (which is from this lessons learned paper) shows that most use is in the late afternoon and early evening. Figure 7 (which is also from this paper) shows that most charging occurred fairly close to home (i.e., 70% within 20 miles); Figure 8 shows that much of the charging that occurred close to home was not because the Leaf could not get home. From this information, one can reasonably assume that DCFC was frequently used to extend the day’s activities.

Another role that DCFC fulfills for AEV drivers is to enable travel between urban areas. Similar to extending the day’s activities, this role is also based on travel needs.

Therefore, DCFC stations can be thought of, not as a convenience associated with another destination, but as a destination for charging.

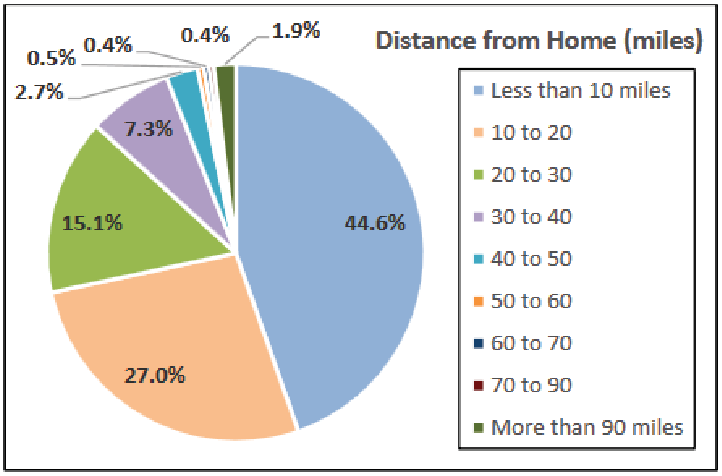


Figure 7. Distance from home where PEV drivers used the most popular DCFCs.

Average SOC%	Full EV Project	July-December 2013
All	35.40%	33.10
Less than 10 miles from home	34.35%	31.90%

Figure 8. Average state of charge percent and miles from home at start of charge.

4.3.3.1 Obstacles to Deployment and Use. The primary obstacle to deployment of DCFC stations is cost; both cost of the units and cost of installation. Similar to AC Level 2 EVSE hardware costs, the cost of the fast-charge stations are falling from the over $50,000 prices of 2011 to prices well below $20,000 today. Again, similar to installation costs for commercial AC Level 2 stations, the installation costs for DCFC are significant. In addition, similar to commercial AC Level 2, they are not affected by any economies of scale. Each installation is its own construction project and, in the case of DCFC, frequently includes incremental electrical service obtained from the local electric utility.

For those AEV drivers seeking a fast charge, the primary obstacles to use are cost to charge and an insufficient number of DCFCs. Although the cost to use DCFC is an obstacle to greater use, the use of DCFCs fulfills a charging need. This is reflected in results from the input of industry experts, with 60% of whom felt that the cost to charge was a factor for charger use, but not critically so. While 60% felt that the cost to charge was the critically important factor in deciding to use publicly accessible AC Level 2 stations. Because use of a DCFC is need based, the current insufficient quantity of DCFC stations is the most significant obstacle to accumulating electric miles.

Another factor that affects both deployment and use is demand charges. These charges do not affect deployment until they are used and then only if/when the host understands demand charges do they become an obstacle to deployment. A charging site host educated on the impact of demand charges is often unwilling to become a host, which is an obvious obstacle to deployment of charging equipment.

Because the number of AEV drivers increases, so will the need for and consequent use of DCFCs. Because the demand charges are a periodic fee whose impact is spread over use during the billing period, increased use of DCFCs will decrease the impact that demand charges have on the host/operator of the charging station.

4.3.3.2 Overcoming Obstacles to Deployment and Use. The obstacle to deployment associated with DCFC station cost is being overcome through normal technical development of the hardware. This development has introduced smaller, less expensive DCFCs, many of which feature both CHAdeMO and SAE Combo Charging System connectors. However, like AC Level 2 installation costs, the cost to install DCFCs is and will continue to be a challenge.

Electric utility demand charges present a significant obstacle to early deployment of DCFC infrastructure. Demand charges are applied by many electric utilities based on the highest 15-minute average power drawn by the DCFC anytime during the billing month. Therefore, each DCFC will incur a demand charge based on its maximum power on the first charge of the billing month. With typical demand charges ranging from $15 to $25/kW and charge power up to 60kW, one fast charge in a month can generate as much as $1,500 in demand charges. This presents a particularly acute problem for the introduction of DCFCs, which are expected to initially see only a few charges per week. As PEV adoption increases, there will be an associated increase in DCFC use, which will reduce the impact of electric utility demand charges.

A potential means of reducing demand charges is aggregating all DCFCs in an electric utility service territory to pay demand charges on only the coincident load resulting from simultaneously operating DCFCs. This more accurately represents total demand that a network of DCFCs places on the electric grid and will be very effective in reducing demand charges until charge frequency builds to provide a significant number of fast charges to amortize demand charges over.

Clarifying the parking requirements associated with ADA would make installation costs more transparent and provide opportunities for installation cost reductions that result from uniform site requirements.

The Paradox of Fast-Charging

Although over 95% of all electric vehicle miles driven can be fueled by home and/or workplace charging, publicly accessible charging will also be required if PEVs are expected to fulfill all of their operator's driving needs. Fast-charging will play a key role in supporting this need for publicly accessible charging.

AC Level 2 charging, because of the time required for significant charge energy transfer, is most useful at destinations where PEV drivers are engaged in other activities, plan to spend an hour or more, and can take the "opportunity" to charge. Fast-charging, because of the shorter time required for a significant charge energy transfer, has the capability of satisfying a PEV driver's "need" to charge.

Most DCFCs deployed to date deliver a maximum charge rate of 40 to 50 kW. The highest power fast chargers deployed thus far have been in the Tesla Supercharge network, with a maximum output of 120 kW. Fast-charging at power up to 350 kW [6] has even been proposed.

Reducing the time needed to refuel is desirable (some believe it needs to be reduced to the time that it takes to refuel a gasoline vehicle), but fast-charging at these high power levels, while beneficial in shortening charging times and extending vehicle range, also creates several issues that offset the advantages of fast-charging.

- The electric utility's distribution hardware to support DCFC is rarely in place, particularly along transportation routes where DCFCs are typically placed. New distribution transformers and often a line extension or extension upgrade is required. The additional cost of this installation work seriously impacts the DCFC's overall installation cost and, therefore, the economics of a high-power fast-charging.
- The electricity service rate for a 50 kW load (even more so for a 120 or 300 kW load) will almost always include demand charges based on the highest power level consumed during the month. These charges can exceed $20 per kW. This will have a significant impact on the operating costs of a high-power DCFC.
- Fast-charging is a significant and intermittent load that typically occurs during the peak operating hours of the electric grid. Therefore, it is detrimental to efficient operation of the grid, representing a challenge for both capacity and load management.

Installation and operation of fast-charging is a balance between the desire for rapid charging and the negative impact that high power and on-peak demand have on the electric grid.

5. ROADMAP MATRIX OVERVIEW

The Roadmap matrix (Figure 3) defines priorities for charging infrastructure installation as the PEV market phase matures from early stage to mature (i.e., increasing vehicle adoption, with increasing public awareness) and PEV type performance progresses from PEV-40 to AEV-300 (i.e., increased range, with lower cost). The charging infrastructure presented in the Roadmap matrix identifies (for a given maturity phase) the highest priority charging infrastructure that fulfills the EV Everywhere Grand Challenge objectives of promoting PEV adoption and increasing electric miles driven. As the market phase matures, charging infrastructure from the previous phase continues to support its PEV type and typically supports technology progression to longer-range PEV types (i.e., PEV-40 to AEV-100 to AEV-300). In this way, the recommended charging infrastructure provides a coordinated and perpetual infrastructure that continues to meet EV Everywhere Grand Challenge objectives.

It is important to note that charging infrastructure, other than that presented in the Roadmap matrix, may still promote PEV adoption and/or increased electric miles driven if it is used. However, the results will not be as great as can be achieved with a focus on the recommended infrastructure of the Roadmap matrix. Nor will the infrastructure necessarily complement the maturing markets and advancing technology.

It is also important to recognize that residential charging infrastructure supports all PEV types. Throughout development of a mature charging infrastructure, residential infrastructure will continue to be the preferred means of charging and will supply the greatest number of electric miles driven. It is unquestionably the most convenient and, excepting subsidized charging, is also the least expensive. Therefore, investment in residential charging infrastructure will provide universal and long-term support of EV Everywhere Grand Challenge objectives.

Similarly, workplace charging is the most important away-from-home charging location that supports the transitional phase of market maturity for both PEV-40 and AEV-100 vehicle types. Finally, DCFC is an effective long-term means to provide away-from-home charging for both AEV-100 and AEV-300 PEV types that extends daily travel within an urban area and, when needed, can be used to connect adjacent urban areas for the PEV driver.

6. SUMMARY

As highlighted in the EV Everywhere Grand Challenge, vehicle technology is advancing toward an objective to, "… produce PEVs that are as affordable and convenient for the average American family as today's gasoline-powered vehicles …" by developing more efficient drivetrains, greater battery energy storage per dollar, and lighter weight vehicle components and construction. With this technology advancement and greater performance, charging infrastructure is needed to support vehicle adoption and to maximize the electric miles driven. The EV Everywhere Charging Infrastructure Roadmap was developed to prioritize the charging infrastructure deployment targets in support of this EV Everywhere Grand Challenge objective.

This Roadmap follows on from studies conducted by DOE and others, including The EV Project, which to date is the largest deployment and study of PEV charging infrastructure ever undertaken. Data from the EV Project and several of these other DOE supported infrastructure studies were the subject of an all-encompassing summary report titled, "Plug-in Electric Vehicle and Infrastructure Analysis" [3]. This report and others published by INL were consulted frequently to establish Roadmap strategies. Some of the relevant results that influenced the Roadmap include the following:

- 85% of all charging takes place at home
- When workplace charging is available to the PEV driver, 98% of all charging takes place at home or at the workplace

- When drivers charge at their workplace, their daily electric miles travelled increase by 15%
- 22% of the time that drivers charge at work, this charging is necessary to meet their day's driving requirements.

Even though the Roadmap is focused on the priorities for deployment and use of charging infrastructure, the PEVs that are being charged vary, as well as their charging needs. Battery size, capability to fast-charge, and use of a range extender all impact the vehicle's charging. The EV Everywhere Grand Challenge identified three different plug-in vehicle categories:

- PEV-40 – Plug-in hybrid electric vehicle with an all-electric range of approximately 40 miles
- AEV-100 – All-electric vehicle with a range of approximately 100 miles
- AEV-300 – All-electric vehicle with a range approaching 300 miles.

The Roadmap uses these vehicle categories to assess charging infrastructure requirements that are based on vehicle capabilities.

The Roadmap classifies the charging infrastructure being deployed by two characteristics: charging station type and charging station location (referred to in the Roadmap as the **what** and **where**). The **what** of charging infrastructure classifications include the following:

- AC Level 1 – typically with a charge rate below 2.0 kW
- AC Level 2 – stations deployed have charge rates between 3.0 and 10.0 kW
- DCFC – stations deployed typically have charge rates between 20 and 120 kW.

The "where" of charging infrastructure includes the following:

- Residential – AC Level 1 or AC Level 2 charging infrastructure located at the PEV's overnight parking location and charging intended to provide a full charge.
- Workplace – AC Level 1 or AC Level 2 charging infrastructure located at business locations and providing access to charging while the PEV driver is at work.
- Publicly accessible – AC Level 2 away-from-home charging located at trip destinations that will occupy the PEV driver for an hour or more and is available for use by any PEV.
- Intra-urban fast-charging – DCFC infrastructure at convenient locations within an urban area and providing range extension for additional electric miles driven within a metropolitan area.
- Inter-urban fast-charging – DC Fast-charging infrastructure located between urban centers and providing range extension for travel between metropolitan areas.

Finally, the Roadmap defines the phases that a maturing PEV market goes through (referred to as **when** in the Roadmap). These market maturity phases are described as follows:

- Early Stage – PEV adoption by innovators and early adopters who are satisfied that the vehicle range can meet their daily transportation needs using only residential charging overnight. There is little away-from-home (i.e., publicly accessible, workplace, intra-urban, and inter-urban fast-charging) infrastructure in place. PEV adoption and use are not dependent on away-from-home charging.
- Transition – The number of vehicles in the local market increases and the density of deployed away-from-home charging infrastructure. Utilization of away-from-home charging increases as PEV drivers become familiar with the location and use of away-from-home charging infrastructure, allowing them to expand the use of their vehicles and increase their electric mile driven. With the use of workplace and intra-urban DCFC away-from-home charging, early majority adopters become more confident that an AEV-100 can meet their daily transportation needs.

- Mature – Pervasive away-from- home charging infrastructure exists. Increased availability and use of away-from home charging infrastructure allows the all-electric range of vehicles to be extended beyond that provided by an overnight charge at their residential charging infrastructure, resulting in a further increase in electric miles driven. Increased vehicle capabilities, specifically the availability of a competitively priced AEV-300, enables the late majority PEV purchasers to select AEV-300s and meet their charging needs, predominately with at-home charging, and travel between metropolitan areas provided by inter-urban DCFC.

Using the type and location of charging infrastructure definitions, the Roadmap prioritizes the PEV charging infrastructure to be deployed as the PEV market matures from early stage to mature. The Roadmap matrix reflects charging infrastructure prioritization based on analysis of recent data regarding use of PEVs and use of charging infrastructure, as well as their expected ongoing technical development.

6.1 Overcoming Obstacles to Infrastructure Deployment and Use

There are obstacles to future deployment of charging infrastructure and its use, and to the use of existing charging infrastructure. These obstacles are identified and discussed in the Roadmap. The following initiatives have demonstrated effectiveness in overcoming these obstacles:

6.1.1 Use

1. Residential charging – Fully implement time-of-use or electric vehicle charging rates that encourage off-peak charging by providing cost savings for energy used off peak
2. Away-from-home charging
    a. Promote use with ‘no charge to charge’ programs
    b. Support EV industry charger location apps such as Plugshare
    c. Additional vehicle sales and charging infrastructure deployment
    d. Implement/enforce penalties for ICE-ing of charging stations
3. DCFC
    a. Aggregate demand for billing purposes.

Following the EV Everywhere Charging Infrastructure Roadmap for an individual PEV market will help local governments, utilities, EVSPs, and others prioritize what charging station types to deploy and where they would be located to best promote PEV adoption and get the use that would increase electric miles driven.

While most U.S. markets are still in the early stage phase of market maturity, there are a few in the transitional phase. However, in either case, prioritizing efforts to simplify residential installations and encourage workplace charging will be the best way to maximize the ability of the installed charging infrastructure to meet the EV Everywhere Grand Challenge to promote PEV adoption and increase electric miles driven.

6.1.2 Deployment

1. Residential charging
    a. Residential building code requirements for pre-wired charging circuit in the garage of single family homes
    b. Streamline permitting process
2. Away-from-home charging
    a. Commercial building code requirements for dedicated circuits for charging stations
    b. Clarify ADA requirements for PEV charging

c. Continuation of investment tax credits for PEV charging stations

3. DCFC

   a. Clarify ADA requirements for DCFC.

7. CONCLUSIONS

The contents of the Roadmap matrix highlight the following;

- Home charging is the most important PEV charging location for all vehicle types and during all phases of maturity.
- Workplace charging is the next most important charging location and is an effective way to maximize electric miles driven.
- During the early stage and transitional phases of charging infrastructure development, DCFC provides a means for extending intra-urban AEV travel.
- During the mature stage of charging infrastructure development, DCFCs enable inter-urban travel for AEV-300 PEVs.

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Appendix A
Summary of Questionnaire Results

PEV Charging Infrastructure Roadmap

1. Utilization of which type of away-from-home charging has the greatest impact on electric miles driven?	
Answer Options	**Response Percent**
Workplace	75.0%
Publicly Accessible AC Level 2	0.0%
Publicly Accessible DCFC	25.0%

2. Availability of which type of away-from-home charging has the greatest impact on PEV adoption?	
Answer Options	**Response Percent**
Workplace	71.4%
Publicly Accessible AC Level 2	10.7%
Publicly Accessible DCFC	17.9%

3. Which type of publicly accessible charging station has the greatest impact on electric miles driven?	
Answer Options	**Response Percent**
AC Level 2	18.5%
Intra-Urban DCFC (DCFC within an urban area)	25.9%
Inter-Urban DCFC (DCFC between urban areas)	55.6%

4. How important is the cost to charge when deciding to use DCFCs?	
Answer Options	**Response Percent**
Very important factor	39.3%
Important, but not a critical factor on use	60.7%
Not important	0.0%

5. How important is the cost to charge when deciding to use publicly accessible AC Level 2 charging stations?	
Answer Options	**Response Percent**
Very important factor	59.3%
Important, but not a critical factor on use	40.7%
Not important	0.0%

6. How important is multi-family charging infrastructure to the overall objective of promoting PEV adoption?	
Answer Options	**Response Percent**
Very important	53.6%
Important	28.6%
Low importance when compared to other charging infrastructure needs	17.9%
Not important for promoting PEV adoption	0.0%

7. What organization is best suited to deploy and operate publicly accessible charging infrastructure?	
Answer Options	**Response Percent**
Government	0.0%
Electric Utility	60.7%
Oil/Energy Company	0.0%
For Profit Company	21.4%
Other (please specify)	17.9%

Number	Response Date	Other (please specify)
1	**May 4, 2016**	Public-private partnership between government, utility, and for-profit EVSP
2	**April 29, 2016**	Private companies with some government funding
3	**April 28, 2016**	Electric utility; in some cases a for profit company may also bring some value (but not the 100% coverage that EVs need)
4	**April 27, 2016**	OEMs
5	**April 25, 2016**	Depends on local EV readiness and utility participation

8. How important are tax incentives to the deployment of publicly accessible infrastructure?	
Answer Options	**Response Percent**
Critically important to promote infrastructure deployment	53.6%
Helpful, but not critical to infrastructure deployment	46.4%
Not helpful	0.0%

9. Considering the following types of travel, how important is publicly accessible charging (both AC Level 2 and DCFC) to support that type of travel?				
Answer Options	**Not Important**	**Important**	**Critically Important**	**Rating Average***
Work Commuting	17	10	1	2.57
General Intra-city Travel	7	18	3	2.14
General Inter-city Travel	1	9	18	1.39
Commercial Business/Fleet	9	12	7	2.07

10. How much does the cost and inconvenience of residential permitting and inspections impact the adoption of PEVs?	
Answer Options	**Response Percent**
Significant hindrance	6.9%
Hassle, but not a significant impact	72.4%
No impact	13.8%
Don't know	6.9%

11. How important are tax incentives for home charging infrastructure to PEV adoption?	
Answer Options	**Response Percent**
Critically important	17.2%
Helpful, but not critical to PEV adoption	79.3%
No influence on PEV purchase decision	3.4%

12. How important is it to be able to program the charge time for at-home charging stations?	
Answer Options	**Response Percent**
Critically important	34.5%
Important	55.2%
Not important	10.3%

13. Considering the programming of the charge start time for home charging, which of the following should be programmable?	
Answer Options	**Response Percent**
Vehicle	37.9%
Home charging unit	17.2%
Either	24.1%
Both	20.7%

14. When considering the various factors associated with the selection and installation of at-home EVSE, how important is each of the following factors?

Answer Options	Critically important	Important	Not important	Rating Average *
Cost of the EVSE hardware	19	10	0	1.34
Cost of the EVSE installation	19	10	0	1.34
The EVSE Smart features (e.g. programming, use data, etc.)	3	12	14	2.38
The cost and inconvenience of permitting and inspections	2	22	5	2.10
Plugged versus hardwired installation	1	14	14	2.45
The physical size of the EVSE	4	9	16	2.41
The substance of the company standing behind the EVSE	10	15	4	1.79

* - Rating Average shown for questions 9 and 14, assigns the value of 1, 2, and 3 to the level of importance and averages the entries. The lower the number, the more important the item.

15. Demand Charges: Many electric utilities impose demand charges on hosts when power exceeds a threshold, which affects most DC Fast Chargers deployed to date, and many popular multi-unit AC Level 2 sites. Based on your experience, what would you recommend as the most effective way to mitigate the impact that this has on deployment and use?

Answer Options	Response Percent
Demand cost should be paid by PEV drivers using the charging station through standard fees that would incorporate expected demand cost	24.1%
Limit the charger output to avoid demand charges	31.0%
Eliminate demand charges for PEV charging using local energy storage for an additional fee	44.8%

16. Smart Charging: How important is it that hosts or utilities have the ability to control away-from-home charging stations in order to manage electricity costs or grid impact?

Answer Options	Response Percent
Critically important	17.9%
Important	75.0%
Not important	7.1%

17. Recently some PEV manufacturers have introduced free charging for a limited time for buyers of new PEVs as a way to promote PEV adoption. This addresses the cost to charge away-from-home, and therefore encourages use. Do you think this has this been an effective way to encourage PEV adoption?	
Answer Options	**Response Percent**
Yes	75.9%
No	13.8%
Don't know	10.3%

18. Considering the limited time free charging from the previous question; Is this an effective way to increase electric miles driven by encouraging away-from-home charging?	
Answer Options	**Response Percent**
Yes	51.7%
No	31.0%
Don't know	17.2%

19. Please provide any other input that you may have regarding charging infrastructure deployment and use, which impacts the objectives of increasing electric miles driven, and promoting PEV adoption.

Number	Response Text
1	Free charging given OEMs has greatly increased charger congestion, given some drivers negative experiences
2	Need to ensure adequate number of DCFC units to support the number of PEV's in the area.
3	Leverage Alternative Fuel Data Center charge location information by making charge point real-time data readily available to public in a mobile app (e.g., similar to Waze); explore approach of residential EVSE sharing/renting (e.g., like AirBnB)
4	I think that the ICE-ing issue is important if one believes that publicly available charging is critical. Steps should be taken to address this issue with signage, education, penalties, and enforcement. I also think that the business model for publicly available charging is free charging with the EVSE owned by the nearby business(es) to keep customers from a desirable demographic in the store(s) longer.
5	Promote education within multi-unit dwelling communities
6	I don't want my utility limiting my options on EVSE
7	From a consumer perspective, the purchase of a PEV and the new refueling paradigm should be easily understood and as hassle free as possible. Workplace charging is a good way to increase electric miles driven and the halo effect certainly increases PEV adoption.
8	I think you should have had a question on the value of DCFC vs. ACL2 for public -public charging and a little bit more discussion on range anxiety.
9	Free charging is great but if a driver has to go out of their way to utilize the charging then the benefit is neutralized. Workplace charging, preferably free charging, is THE biggest factor in PEV adoption, in my opinion.
10	Publicly accessible ACL2 is a convenience charge, but home and DC fast charging are very important part of both promoting PEV adoption and increasing electric miles driven

11	Question 3 has 3 answers: PHEVs/EREVs care only about L2; BEVs in MDUs will care most about intra-urban DC; all other BEVs will care most about inter-urban DC. Question 6 - MDUs will adopt EVs when intra-urban DC is available (easier than L2 within every MDU). Question 14 - ignores the importance of L1. Question 15 - I think TOU rates will help us all manage DC demand charges (make it cheaper after 6pm to use DC, e.g.). Question 16 - only the customer should be able to "control" his/her vehicle charging - the utility can only offer TOU (for example) to encourage a different behavior.
12	Demand Charge question is really only a problem with DCFC that are rarely used. Once use of the station is high enough, then the demand charge is negligible and would be more cost effective than a higher energy rate with no demand charge.
13	Charging infrastructure fees should be used to encourage non-residential EVSE use only by those that need it most. Limited charging infrastructure will then be available to those that need it most. This is an important demand-control mechanism that should be implemented from the start of a non-residential charging operation.
14	First, you need to re-read question 17, it doesn't flow and needs words removed. Second, in the adoption of PEVs it is important to show consumers they will be able to go on vacation, they will be able to find a charging station off the freeway, just like they can a gasoline vehicle. And, three it is also important to have access to remote charging, such as with AAA. This is simple peace of mind for consumers as they are looking to adopt PEVs.
15	Free charging programs are a double-edged sword. Promote convenience charging which increases congestion. Also, customer should have ultimate control over their own charging, but should be responsive to opting into smart charging programs operated by utilities to encourage demand response.

Appendix B
Questionnaire Responders

Members of the following organizations provided PEV industry input to the Roadmap via their responses to the Roadmap questionnaire.

- Plugshare
- Puget Sound Energy
- Sacramento Municipal Utility District
- General Motors
- Alabama Power
- California PEV Collaborative
- Clean Cities - Tucson
- Clipper Creek
- Intertek - Transportation Technologies
- U.S. DOE Office of Energy Efficiency and Renewable Energy
- INL
- JRP Consulting
- CSRA
- Clean Cities - San Diego Region
- Center for Sustainable Energy
- California Energy Commission
- Clean Cities - Columbia Willamette
- ChargePoint
- Durst Energy Management
- BMW
- U.S. CAR
- Clean Cities - San Francisco.

Appendix C
List of ETEC Projects Conducted from 1989 through 2011

Airport Ground Support Equipment Fast Charging: Design, develop, construct, and operate fast charge systems for charging ground support equipment owned by Southwest Airlines

Level 2 Public Charge Stations: Design, develop, operate, and maintain an array of public charge stations in Phoenix, Arizona.

Nationwide Charge Infrastructure Support – DaimlerChrysler: Provide Level 2 and Level 3 charge infrastructure design and installation for Chrysler EPIC vehicles sold throughout the United States.

Nationwide Charge Infrastructure Support – Ford Motor Company: Provide charge infrastructure design and installation for Ford Ranger electric vehicles sold throughout the United States.

Hybrid Electric Fast Charge Bus Specification and Infrastructure Development: Develop purchase specifications for a hybrid electric fast charge bus for the City of Tempe, Arizona.

Excursion Boat Energy Delivery System: Design, develop, install, test, and maintain a high-efficiency propulsion/charging system for excursion boats operating on Tempe Town Lake in Tempe, Arizona.

Neighborhood Electric Vehicle Charge Infrastructure: Convert neighborhood electric vehicles to fast charge and install a fast charge infrastructure to support their operation at Luke Air Force Base.

Advanced Fast Charge Algorithm Research and Development: Develop practical fast charge algorithms for use in "central fueling" operations for fleet vehicles in support of the Advanced Lead Acid Battery Consortium.

Utility Electric Vehicle Fleet Management – Arizona Public Service: Manage the operations and maintenance functions of the Arizona Public Service Company electric vehicle fleet.

Utility Electric Vehicle Fleet Management – The Salt River Project: Manage the operations and maintenance functions of the Salt River Project electric vehicle fleet.

Develop Electric Vehicle America Technical Requirements: Develop a specification for electric utility purchase of electric vehicles acceptable for utility or government fleet use.

Develop Electric Vehicle Test Requirements: Develop test guidelines and procedures for EV America and DOE for evaluating electric vehicle performance.

EV America Performance Testing: Comprehensive performance testing of 20 converter and OEM electric vehicles using test procedures developed for EV America.

Electric Vehicle Fleet Performance Reporting: Author and publish quarterly reports for Arizona Public Service Company as part of DOE'S Site Operator Program

U.S. Department of Energy Fleet Operations Program: Conduct electric vehicle testing and evaluation of batteries and battery chargers as one of two DOE site operators.

Estimate Electric Vehicle Lifecycle Costs: Estimate electric vehicle lifecycle costs for the Edison Electric Institute and compare to both gasoline and AFV alternatives.

Determine AFV Fleet Operating Costs: Study the operating costs for compressed natural gas and liquefied petroleum gas vehicles in a test fleet environment of the City of Tempe, Arizona.

Station Car Demonstration Program: Develop vehicle requirements, purchase specifications for vehicles to be used as station cars, and implement the Station Car Program by developing and conducting operator and maintenance training and performance reporting.

Bus Fast Charge Demonstration – Specialty Vehicle Manufacturing Corporation: Convert a 20_passenger bus to fast charge, facilitating three charges per day, and extending bus range to over 100 miles/day

Transportable Electric Bus Charger: Develop a mobile charger for Georgia Power Company's electric bus fleet.

Electric Bus Application Engineering – Specialty Vehicle Manufacturing Corporation: Support application of electric buses in transit applications by developing purchase specifications, routing plans, determining range and charging requirements, designing, developing and conducting training for operation and maintenance personnel, installing charge infrastructure, and implementing performance reporting requirements.

Conduct In-Vehicle Battery Testing: Evaluate the performance of various battery types in a fast charging environment, including development of special test procedures to evaluate the fleet applicability of battery fast charging.

Electric Vehicle Safety Workshop: Develop, document, and present a 4-hour workshop on the safety of electric vehicles.

Battery Test Vehicle: Design and construct a road-worthy electric vehicle capable of testing battery packs with voltages ranging from 100 to 400 V.

Facilitate Development of EV Fire Fighting Procedures – State of Arizona: Coordinate development of standard operating procedures for fire departments in handling electric vehicle fire and rescue emergencies and structure fires and rescue emergencies involving electric vehicle infrastructure.

Electric Vehicle Risk Analysis: Develop hazard assessments and risk analyses for operation of electric vehicles in a racing competition environment.

Electric Vehicle Race Safety: Develop safety plans for conduct of electric vehicle races, including vehicle design requirements, charging requirements, logistics, and emergency planning and training.

Racing Vehicle Traction System: Develop the drive system for the Brawner Motorsport EX-11 open wheel, Indianapolis-style racecar.

Emergency Responder Briefing Booklet: Develop, print, and distribute a booklet informing emergency responders (e.g., police and fire personnel) of the Impact PreView Program in the Phoenix area. Conduct a "train the trainer" program for key emergency responders.

MSDS Booklet: Compile Material Safety Data Sheets for electric vehicle batteries.