U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Status and Issues for Plug-in Electric Vehicles and Hybrid Electric Vehicles in the United States

Alternative Fuel and Advanced Vehicle Technology Market Trends

Argonne National Laboratory

Danilo J. Santini, Yan Zhou, and Marcy Rood Werpy

February 2015

Clean Cities
U.S. Department of Energy

Strategies and Issues for Plug-in Electric Vehicles and Hybrid Electric Vehicles in the United States

Alternative Fuel and Advanced Vehicle Technology Market Trends

Danilo J. Santini
Yan Zhou
Marcy Rood Werpy
Argonne National Laboratory

February 2015

Prepared by
ARGONNE NATIONAL LABORATORY
Lemont, IL 60439
managed by
U-CHICAGO ARGONNE, LLC
for the
U.S. DEPARTMENT OF ENERGY

Abstract

Electric drive vehicles discussed in this report are defined below under categories (a) to (f). The now widely used ambiguous term PEV (plug-in electric vehicle) can mean any of the options (b) to (f).

(a) hybrid electric vehicle (HEV). The HEV uses batteries but has no plug. An engine and gasoline provide most of the energy for movement.

(b) plug-in hybrid electric vehicle (PHEV). The PHEV has a battery charge depleting (CD) range less than 30 miles. The engine in most available versions comes on during CD mode.

(c) extended range electric vehicle (EREV). The EREV has a charge depleting range of 35 to approximately 70 miles or more. The engine never comes on during CD mode. EREVs are often considered PHEVs. We generally distinguish them from PHEVs as in (b) for greater accuracy.

(d) range extended battery electric vehicle (BEVx). The BEVx has a CD range of 70 miles or more and a small gasoline engine and fuel tank allowing range to be approximately doubled.

(e) battery electric vehicle (BEV). Most of today's BEVs have a range of less than 100 miles.

(f) performance BEV. The Tesla Model S has a range of about 200 miles, high power and rapid acceleration. Chevrolet has plans to produce a 200 mile BEV within the next 5 years.

Electric drive in the U.S. is a 21st century technology whose commercial success began with HEVs using nickel metal hydride (NiMH) battery chemistries introduced by several automakers. The overall U.S. history of the NiMH HEVs was an increasing success in passenger cars, but a failure in light-duty trucks. The later emergence of more powerful and compact batteries using various lithium-ion (li-ion) chemistries, as oil prices were steadily rising from 2002 to early 2008, resulted in significant enthusiasm first for PHEVs, and then BEVs. Expanding electric drive vehicle types and capabilities have resulted in increasing coverage of the highway vehicle market, both private and commercial. The following are the top five market niches identified in this report:

1. PHEVs and EREVs with workplace charging. This is a focus. It does not mean other PEVs should be excluded. How and whether to assess fees for charging at the workplace is a topic of discussion and evaluation. Avoiding EVSE electronic measurement equipment can lower EVSE cost by considerably more than half. Reduction of record keeping also reduces administrative cost.

2. BEVs and possibly EREVs & BEVx in air quality nonattainment areas. This niche includes (but is not confined to) states that have adopted California light-duty vehicle emissions standards and/or signed a memorandum of understanding (MOU) to promote PEVs that obtain zero emissions vehicle (ZEV) credits under the CA standards. Since the largest metro areas tend to have the most difficult air quality problems, the encouragement of BEVs requires installation at a high proportion of multi-unit dwellings (MUDs), which has been found to involve high financial and management costs. Attention to MUD EVSE feasibility and/or development of workplace and other charging alternatives is particularly valuable in this niche. Working with developers, building owners, and operators, as well as associated professional organizations, will be crucial.

3. PHEVs, EREVs and BEVx's in cold climates. In coldest conditions engines often provide cabin and battery pack heat with lower GHG emissions than electricity from fossil fueled generation from the grid, while the engine and gasoline greatly enhance cold temperature range. Extreme losses of range for BEVs parked outdoors off the grid during cold snaps combined with snowstorms are particularly problematic. Consumer and dealer education is instrumental for this niche.

4. PHEVs, EREVs, and BEVx's in new construction (generally outer suburban). This minimizes EVSE cost. An important strategy is to write codes to impose pre-installation of conduit to support

future installation of wiring and EVSE as demand emerges. Working with home builders, developers and their professional associations will be critical.

5. BEVs, medium & heavy electric drive trucks, and electric drive buses in dense urban areas. Commercial applications operating with many stops per mile at low average and top speed for many hours per day, most days of the week represent the heart of this market niche. A complicating matter for potential purchasers is that there are no estimates of fuel economy for medium- and heavy- duty vehicles on current government websites.

This paper includes a summary of federal support in terms of incentives and mandates on electric drive vehicles, existing DOE Clean Cities' activities, and strategies to expedite the planning for and development of infrastructure and the targeted growth of the marketplace. Past and current electric drive market status is summarized. Trends are interpreted. Federal and state support combinations (credits, PEV Readiness Grant projects, and the EV Project) have contributed to success of PEVs. PEVs currently are available in diverse models covering more vehicle classes and types than for HEVs.

Two of the five market niches that we identify should vary with respect to the degree of financial incentives to be given to BEVs vs. other PEVs. States with air quality problems (niche 2) should emphasize all electric operation, with greater incentives for BEVs, and perhaps incentives for EREVs and BEVx vehicles. States with cold climates (niche 3) might choose not to subsidize BEVs, but subsidize PEVs with gasoline engines. Elsewhere, a balance similar to Federal incentives would be reasonable. Air quality is still a strong motivation for both federal and local governments to promote PEVs, especially BEV adoption (niche 2). Net upstream emissions effects and resulting air quality impacts from charging PEVs can vary considerably, depending on the PEV technology, the electrical grid mix in the location where charging occurs, and the hours of the day that charging takes place. The charging strategies promoted by "Smart grid" and "time-of-use" (TOU) electric rates have been encouraging charging at night when power generation needs are lowest. Unfortunately, in many locations this leads to more coal use by PEVs. This increases GHG, particulates, and sulfur oxides emissions attributed to PEVs.

There is a narrowing and shrinking charge point market size hierarchy from (1) residential to (2) workplace to (3) public charging for PEVs. Available information suggests that over two-thirds of the fleet of California PEVs are sometimes used for work trips, while well over half are consistently used on workdays. Trends in the mix of PEV technologies and their electric range will interact with the degree of need for workplace charging, as well as the mix of EVSE types needed. PHEVs and EREVs would benefit from judiciously installed new low power and cheaper (than for BEVs) infrastructure designed specifically for safety and convenience in this new application. New slightly higher capacity circuits than provided under existing 120V standards may prove very important for these PEVs and for the successful resale of BEVs.

Current evidence is that BEVs are more often chosen for use in central cities. This may be the primary reason BEVs are driven less annual miles than PHEVs, EREVs, and performance BEVs, which are more often found in suburbs. An overarching question is whether PHEVs combined with workplace charging (niche 1) will ultimately electrify more miles than EREVs, BEVs and BEVx's needing less extensive workplace charging. Suggestions for future charging infrastructure deployments take into account the higher required EVSE power that supports pure electric BEVs.

Combinations and permutations of electric drive and conventional-drive in PEVs and HEVs are extensive and expanding. This complicates consumer choices considerably, even without considering infrastructure aspects. Improvement of already extensive consumer information tools seems to be necessary to help narrow individual consumer choices among these numerous technologies. The dealer experience of PEV purchasers has proven to be much worse than for conventional vehicles. The purchase experience at dealers needs to be improved through focused consumer information tools assuring that electric drive advantages in the most effective market niches are clearly illustrated. Several judgments about future directions, with a bit more detail relative to market niches, close the paper.

Table of Contents

Figures:

Tables:

1. Light Duty PEV Types

Electric drive vehicles discussed in this report are defined below under categories (a) to (f). The now widely used ambiguous term PEV (plug-in electric vehicle) can mean any of the options (b) to (f).

(a) hybrid electric vehicle (HEV). The HEV uses batteries but have no plug. An engine and gasoline provide most of the energy for movement.

(b) plug-in hybrid electric vehicle (PHEV). The PHEV has a battery charge depleting (CD) range less than 30 miles. The engine in most available versions comes on during CD mode.

(c) extended range electric vehicle (EREV). The EREV has a charge depleting range of 35 to approximately 70 miles or more. The engine never comes on during CD mode. Thus, it has zero tailpipe emissions during charge depletion.

(d) range extended battery electric vehicle (BEVx). The BEVx has a CD range of 70 miles or more and a small gasoline engine and fuel tank allowing range to be approximately doubled.

(e) battery electric vehicle (BEV). Most of today's BEVs have a range of less than 100 miles

(f) performance BEV. The Tesla Model S has a range of about 200 miles, high power and rapid acceleration. Chevrolet has plans to produce a 200 mile BEV within the next 5 years.

As one moves from (a) to (f), the size, energy, and power of the battery packs increase and the share of electric driving generally increases. However, electric power levels for the EREV, BEVx and standard BEV categories are similar. Policy relevant "kinks" exists between the PHEV and EREV, where gasoline engine operation is eliminated during CD. Another kink is between the BEVx and BEV, where the gasoline engine is completely eliminated. These kinks affect current and future policies related to air quality. They also affect the amount of oil and greenhouse gases (GHGs) saved. The air quality kinks have important market niche implications for the share of fully electric vehicles likely to be sold in a metro area (or state). Under existing California regulation, during the next few years, up to half of zero emissions vehicles (ZEVs) to be sold in the ten states that have adopted California emissions standards for light duty vehicles may actually be BEVx vehicles. In very cold conditions, shown to be relevant in this paper, an engine can provide vehicle cabin and battery warm-up heat with lower GHGs than a battery. The now widely used ambiguous term PEV (plug-in electric vehicle) can mean any of the above options from (b) to (f). This report attempts to carefully choose the appropriate acronym or set of acronyms among (b) to (f), generally avoiding use of the term PEV.

Although we predominantly discuss relatively viability of PEV models (b) through (e), it is worth noting that type (f), the Tesla Model S with 200+ mile electric range with high power is a unique luxury technology that could remain competitive even with low gasoline price. This is implied by the fact that Chevrolet also intends to produce a 200 mile BEV in the next five years.

2. Opportunities and Market Niches

The following are the top five market niches identified in this report:

1. PHEVs and EREVs with workplace charging. This is a focus. It does not mean other PEVs should be excluded. How and whether to assess fees for charging at the workplace is a topic of research and debate. Workplace charging feasibility may be greatly enhanced if the IRS and/or Congress specify rules with respect to conditions under which free or subsidized workplace charging could be provided to employees and costly record keeping avoided, if at all. Nicholas and Tal (2013) have recently argued that free workplace charging is detrimental to efficient use of workplace EVSE. As long as the employer avoids electricity demand charges, the average incremental cost of electricity charging PHEVs or EREVs at workplaces should generally be on the order of a dollar or less per day of actual charging. Given typical commercial electricity rates, the total annual electricity cost per PHEV or EREV should be below $250, considering holidays, vacation days, and sick days. However, fuel taxes are thereby avoided and costs of the electric vehicle supply equipment (EVSE) installation are not included. Avoiding EVSE electronic measurement equipment can lower EVSE cost by considerably more than half. Reduction of record

keeping also reduces administrative cost. Particularly when fast charging is made available, BEVs given free charging at higher kW than applicable to PHEVs and EREVs could achieve more benefit for BEV owners charging only at work. The potential for negative opinions by the majority of employees about receipt of free electricity by PEV owners is an area of "equity" concern that could slow workplace charging, as is the right to park where EVSE installation is least costly (close to buildings).

2. BEVs and possibly EREVs & BEVx in air quality nonattainment areas. This niche includes (but is not confined to) states that have adopted California light duty vehicle emissions standards and/or signed a memorandum of understanding (MOU) to promote PEVs that obtain zero emissions vehicle (ZEV) credits under the CA standards. Since the largest metro areas tend to have the most difficult air quality problems, the encouragement of BEVs requires installation at a high proportion of multi-unit dwellings (MUDs), which has been found to involve high financial and management costs. Attention to MUD EVSE feasibility and/or development of workplace and other charging alternatives, is particularly valuable in this niche.

3. PHEVs, EREVs and BEVx's in cold climates. In coldest conditions engines often provide cabin and battery pack heat with lower GHG emissions than electricity from fossil fueled generation from the grid, while the engine and gasoline greatly enhance cold temperature range. Extreme losses of range for BEVs parked outdoors off the grid during cold snaps combined with snowstorms are particularly problematic.

4. PHEVs, EREVs, and BEVx's in new construction (generally outer suburban). This minimizes EVSE cost. An important strategy is to write codes to impose pre-installation of conduit to support future installation of wiring and EVSE as demand emerges.

5. BEVs, medium & heavy electric drive trucks, and electric drive buses in dense urban areas. Commercial applications operating with many stops per mile at low average and top speed for many hours per day, most days of the week represent the heart of this market niche.

3. Current Market Status

Electric drive in the U.S. is a 21st century technology which is rapidly evolving and steadily expanding its coverage of the highway vehicle market. Four years after the first two models (Volt and Leaf) were introduced into the U.S. market, PEV counts for about 0.8% of total light duty vehicle market by the end of 2014. When PEV sales are added to HEV sales, total electric drive sales share of LDV reached 3.45% in 2014. Energy Information Agency (EIA) projects that electric drive vehicle sales share would exceed 8% by 2040 under high oil price (Annual Energy Outlook 2014). A consulting company, Navigant Research, forecasts that the sales share would be close to 7% by 2023 in their base case scenario (Shepard, 2014). As battery technology improves, Navigant also projects that electric-hybrid vehicles will gain more traction in commercial applications, where the technology offers significant benefits for drive cycles that involve a lot of city driving in stop-start traffic. Navigant expects that the sales of electric drive and electric-assisted medium- and heavy-duty commercial vehicles (Classes 3 to 8) will exceed 4% in 2023 in North America, representing a compound annual growth rate of 29% (Alexander, 2015).

3.1 Influence of Battery Technology and Regulation on Electric Drive

The first modern generation of auto-industry-produced battery electric vehicles (BEVs) of the 1990s showed that Ni-MH and lead acid battery technologies were inadequate to support commercial BEVs. However, by the end of the decade Ni-MH proved entirely adequate to support HEVs. The emergence of commercially viable electric drive started at the very end of the 20th century, in Dec. of 1999, when 17 Honda Insight hybrids (HEVs) were sold in the U.S. It was Toyota, however, that made a long-term commitment to the technology, losing money for a number of years before its HEV technology became a core profit maker for the company, available in many different models. HEV batteries prove useful for short bursts of power and energy, but the power and energy cannot be sustained for long periods. This is a deficiency with respect to steady hauling of heavy loads. The overall U.S. history of the NiMH HEVs was increasing success in passenger cars, but failure in light duty trucks (Fig. 1). The first HEV light truck was introduced in 2004, five years after the Insight. Engine downsizing to obtain greater fuel efficiency as a part of HEV powertrain optimization was acceptable in passenger cars but not in trucks, which more often had to carry or tow heavy loads. Market share in light duty trucks never matched that in passenger cars, and subsided after peaking at barely 1% in 2009 (Fig. 1).

Attempts to introduce electric drive vehicles in the 1990s were a product of anticipated technology viability followed by regulatory pressure in Japan and California. The California ZEV regulation requiring ZEV technology by the end of the decade had followed a 1990 General Motors announcement at the Los Angeles motor show of plans to produce a BEV, showing a prototype. While the U.S. also created regulations in the Energy Policy Act of 1992 to require fleets of Energy Providers, and Federal and State fleets to incorporate increasing shares of Alternative Fuel Vehicles through the 1990s, this Act was relatively unimportant because it had significant enforcement loopholes and did not include any supporting incentives (Seisler, 2014).

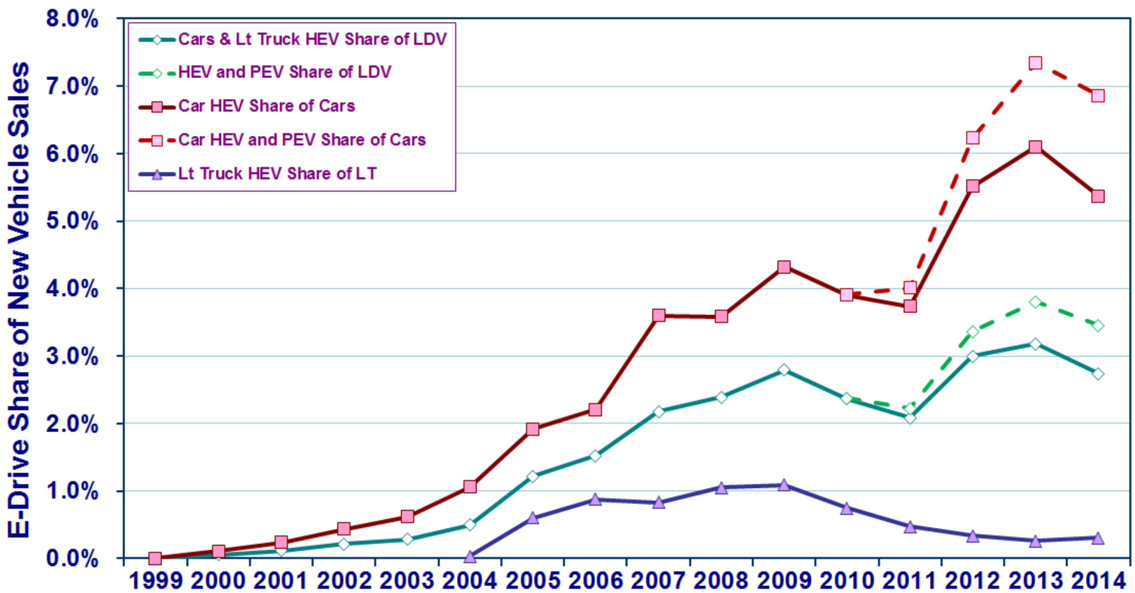


Fig. 1 HEV and Plug-in Vehicle (PEV) Market Share Trends

In the late 1990s battery electric vehicles (BEVs) based on the Ni-MH and lead acid technologies were marketed hesitantly by several large automakers, only in California, to show progress toward meeting ZEV regulations. Only automakers selling large volumes of vehicles in California had to introduce the first wave of ZEVs. The ZEV regulation was designed to incentivize BEVs and/or fuel cell vehicles (FCVs). FCVs are another technology capable zero tailpipe emissions operation. FCVs had much longer range than the BEVs of the time. As was true for batteries and power electronic equipment in the 1990s, fuel cell costs were very high. Fuel cell costs have since come down considerably. However, the FCV "Achilles heel" is that the needed infrastructure costs a lot per unit of hydrogen delivered in part because it has to be built from scratch just for the FCVs. Plug-in electric vehicles (PEVs) have the advantage of largely tapping excess capacity of an existing infrastructure previously established for other customers.

The later emergence of batteries using various lithium-ion chemistries, as oil prices were steadily rising from 2002 to early 2008, resulted in significant enthusiasm first for PHEVs and then BEVs. The technically refined, highly efficient second generation U.S. Prius was introduced in 2004. Several small companies in the U.S. and elsewhere began developing plug-in retrofit options. The successfully marketed retrofits made use of compact li-ion batteries that fit in an empty space under the Prius' luggage compartment. Following this, the li-ion equipped two seat Tesla Roadster elevated enthusiasm for BEVs, as its performance capabilities dramatically eclipsed those of the two seat GM Impact of the 1990s using NiMH. Since these developments, li-ion battery technology has been consistently used in an increasing number of PHEVs and BEVs.

3.2 Annual Sales and Model Availabilities

Up to the end of 2014, cumulatively over 287,000 PEVs have been sold in the U.S. with annual sales close to 119,000 units. Although down from the best performance year 2013, still there were over 450,000 HEVs sold in 2014. Figure 2 shows the Federal and state support combinations (credits, PEV Readiness, EV Project, discussed in later sections) have contributed to more rapid market success of PEVs than was the case for HEVs, if one considers share gained from date of first vehicle introduction.

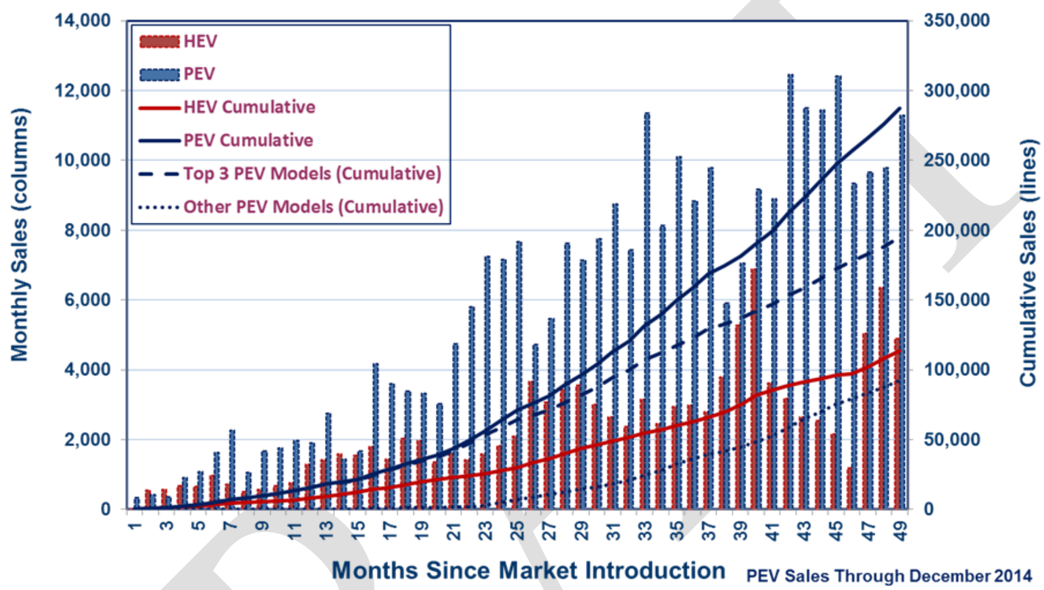


Fig. 2 Market share trends from date of first commercial introduction, HEVs and PEVs

In the first four years the three available plug-in vehicles sold in greater numbers than did the initial three HEVs. Since more models were available in early years, the total sales of plug-in vehicles grew at a significantly greater rate compared to HEVs. Multiple explanations are possible. The first is the combination of incentives mentioned previously. Another factor is the higher number of PEV makes and models introduced. Still another is the diversity of sizes of the vehicles introduced (Fig. 3). Finally, relative (or "real") oil and gasoline prices were at a very high level during the years of introduction. Where HEVs in 2014 were predominantly mid-size cars, plug-in vehicles included significant shares of subcompacts, compacts, and large cars. On average PHEVs are smaller than HEVs, with larger shares of compacts and subcompacts. Because of the success of the large Tesla Model S sedan, and the sales dominance of the mid-size Leaf, BEVs are larger on average than PHEVs. The fact that compliance BEVs are small and introduced in only a few states suggests a cost minimization strategy by many automakers, rather than commitment to national success of these BEVs. The general success of plug-in vehicles can be attributed primarily to shared success of multiple nationally marketed models — the Plug-in Prius, the two Ford Energi PHEVs, the Volt, the Leaf and the Model S. In contrast, for HEVs the singular success of the Prius stands out.

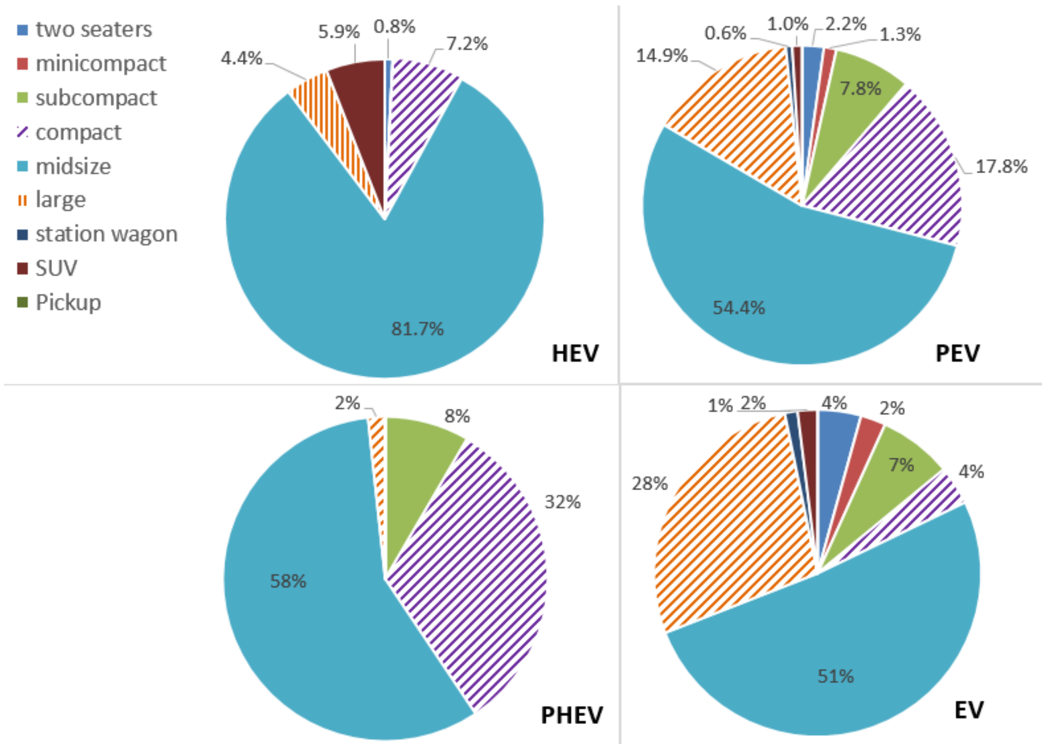


Fig. 3. EPA 2014 size class sales shares for light duty vehicle electric drive technologies

3.3 Electric Drive Vehicle Efficiency

Electric drive vehicle use batteries to store and discharge energy to provide at least some of the movement of the vehicle, which save the petroleum usage. Several types of electric drive vehicles use both engines and gasoline all the time. Battery electric vehicles (BEVs) have no engine and do not use gasoline. EREV and BEVx in CD mode, as well as BEV, have no tail-pipe emissions. However, net upstream emissions effects and resulting air quality impacts from charging PEVs can vary considerably, depending on the PEV technology, the electrical grid mix in the location where charging occurs, and the hours of the day that charging takes place (further discussed in Session 4). Table 1 shows the gasoline and electricity efficiency of current available PEV models.

Table 1 Gasoline and Electricity Efficiency of Current Available PEV Models

Manufacturer	**Model**	**Type**	**All-Electric Range* (miles)**	**Combined Fuel Economy-Electricity (MPGGe)**	**Combined Fuel Economy-Gasoline (MPG)**
BMW	Active E	EV	94	102	
BMW	i3	EV	81	124	
		REx	72	117	39
BMW	i8	PHEV	15	76	28
Smart USA	Smart ED	EV	68	107	
Chevrolet	Volt	PHEV	38	98	37
Chevrolet	Spark	EV	82	119	
Ford	Focus	EV	76	105	
Ford	C-Max Energi	PHEV	21	88	38
Ford	Fusion Energi	PHEV	21	88	38

Honda	Accord	PHEV	13	115	46
Honda	Fit EV	EV	82	118	
Mitsubishi	I EV	EV	62	112	
Mercedes	B-Class	EV	87	84	
Nissan	Leaf	EV	75	114	
Toyota	Prius PHEV	PHEV	11	95	50
Toyota	RAV4 EV	EV	103	76	
Tesla	Model S	EV	208	95	
Tesla	Model S		265	89	
Fiat	500E	EV	87	116	
Porsche	Panamera S E-Hybrid	PHEV	16	50	22
Cadillac	ELR	PHEV	37	82	33
Volkswagen	e-Golf	EV	83	116	
Kia	Soul EV	EV	93	105	
Porsche	Cayenne S E-hybrid	PHEV	14	47	22

Efficiency data from the most recent models at fueleconomy.gov

3.4 Medium and Heavy Duty Electric Drive.

The success of li-ion batteries in light duty passenger cars illustrated to medium and heavy vehicle manufacturers that there should be potential for electrification of their drivetrains as well. In June of 2007, federal tax credits for heavy hybrids (actually medium and heavy – from 8500 GVW and up) were implemented. A plug-in technology for multiple medium duty trucks using General Motors chassis is available from Via Motors (http://www.viamotors.com/). This technology is marketed for use in congested urban delivery and service applications. Eaton developed plug-in powertrains for use in "Bucket Trucks" of Electric Utilities, allowing the trucks to operate electrically at the work site. In January 2015, BYD debuts the world's first long-range, 100% battery-electric, over-the-road coach bus of three 100% battery-electric coaches the company will launch globally this year. Moreover, Zenith Motors LLC, a Kentucky-based electric vehicle manufacturer, has announced that its all-electric shuttle vans are California Air Resources Board approved and now eligible for a California voucher program (up to $50,000). The Transit Authority of River City (TARC), which provides public transportation in the Greater Louisville, Ky., area, has launched a fleet of 10 "ZeroBus" vehicles which were manufactured by South Carolina-based Proterra Inc. and replace TARC's diesel-powered trolleys. XL Hybrids Inc., a Massachusetts-based developer of hybrid-electric powertrain technology, is offering special financing options which will allow customers to retrofit current fleet vehicles and pay for the XL3 hybrid-electric drive system over time. Furthermore, customers can also refinance their existing vehicles or order new vans and buses with the system.

PHEV trucks are not presently listed on the Alternative Fuels Data Center site, but many HEV and BEV trucks are listed, with details available for each (www.afdc.energy.gov/vehicles/search/). There are no regular government vehicle estimates of fuel economy for medium and heavy duty vehicles, so manufacturer information is critical. There are fewer heavy duty than medium duty electric drive options. Heavy duty electric drive is usually confined to HEVs. A competitor and complement to new electric HEVs is the hydraulic hybrid powertrain replacement kit for new and used trucks such as marketed by Lightning Hybrid. It is generally recognized that electric drive powertrains are expensive, requiring very intensive use to pay off. Vehicles used for many days per year, many hours per day, driven at relatively low average speeds are the anchor niche for medium and heavy truck electric drive. Long haul trucks generally do not use electric drive for motive power. However, electrification of cabin comfort and convenience when parked overnight is relatively common. Many of the HEV trucks continue to use Ni-MH, but li-ion is used for plug-ins and will likely be substituted in future HEV models.

Although electric drive currently has only a small share of the total market, major companies with large delivery fleets such as UPS and Federal Express have developed excellent expertise in evaluating the best niche applications for electric drive, taking finances and local regulations into account.

4. Infrastructure and Charging

4.1 Infrastructure Trends

In Fig. 4 the history of electric drive vehicle sales and charge stations added is shown from 1999-2014. It can be seen that the number of chargers and number of BEVs and PHEVs jumped at approximately the same time, starting in 2011. The EV Project, which supported charging station installation, began in 2009 and ended in 2013. It would appear from this plot that early charging station growth led the number of plug-in vehicles, by at least several months. The EV Project was heavily oriented toward support of BEV charging, which at the time meant the Nissan Leaf. In later years, Volts were added, but the vast majority of vehicles were Leafs. The implication is that the EV Project seeded growth of sales of the Leaf in cities which participated. A significant portion of recent growth can also be attributed to the Recovery Act which supported total 10,996 stations/26,709 charging points installed by the end of 2014 which comprise 84% of public access outlets. Table 2 shows the available public and private charging stations/outlets by state.

In Fig. 5 we divided the share of total number of charging outlets (CO) per state as provided by the Alternative Fuels Data Center (http://www.afdc.energy.gov/fuels/electricity_locations.html) by the share of LDVs and plotted it next the PEV/LDV ratio. We also divided the share of 2013 PEVs by state by the share of light duty vehicles (LDVs) and order the results from highest to lowest share (red). Overall, it appears that charge points and PEVs have been spatially matched fairly well, though there are a few apparent mismatches. The major metropolitan areas of the top four states have their relatively mild climate determined by the adjacent Pacific Ocean. Also, recreational travel to mountain areas is relatively easy compared to much of the U.S., so satisfying vacation travel need not be as long a distance as elsewhere. Washington State took advantage of this by creating a fast charging network supporting recreational travel with stations allowing BEVs such as the Nissan Leaf to negotiate the Cascade Scenic Loop Highway (liberally using state highways) which allows day trips (or longer duration) from Seattle (Engeldinger, 2014).

Table 2 Electric Charging Station and Outlets by State and Access, 2014

State	Public		Private		State	Public		Private	
	Station	Charging Outlets	Station	Charging Outlets		Station	Charging Outlets	Station	Charging Outlets
AL	38	62	33	38	NC	209	507	70	175
AK	1	1	-	-	ND	2	3	1	1
AR	29	44	12	13	NE	23	44	2	2
AZ	276	206	36	584	NH	39	68	15	21
CA	2,042	6,347	366	935	NJ	123	324	35	39
CO	196	418	26	76	NM	22	59	4	4
CT	167	337	34	53	NV	89	275	3	3
DC	57	134	6	16	NY	437	990	80	134
DE	14	25	4	5	OH	116	201	44	55
FL	482	1,165	101	140	OK	22	33	12	15

GA	271	623	46	64	OR	380	881	45	113
HI	161	371	32	66	PA	185	321	53	58
IA	49	100	11	22	RI	61	162	3	3
ID	12	21	3	3	SC	127	233	26	27
IL	346	761	70	106	SD	8	29	3	3
IN	93	191	32	46	TN	317	734	72	183
KS	76	168	25	37	TX	564	1,506	144	371
KY	32	128	14	16	UT	58	127	12	21
LA	27	55	20	23	VA	198	540	45	90
MA	271	729	30	36	VT	53	135	4	5
MD	243	573	34	64	WA	456	1,205	96	282
ME	30	48	8	8	WI	154	256	23	51
MI	254	623	41	93	WV	21	91	8	11
MN	197	411	22	49	WY	9	16	1	1
MO	92	171	19	31	**Total**	9,151	22,997	1,845	3,712
MS	16	17	17	18	**%**		86%		24%
MT	6	28	2	2					

4.2 Charging Equipment Standardization Issues.

A significant improvement in the area of electric vehicle supply equipment (EVSE) for the recent generation of BEVs, EREVs and PHEVs has been developed by SAE and automakers working together. Unlike the competition among charging technologies in the 1990s, one standard connector and charge port for level 1 and level 2 charging is now in widespread use. The SAE J1772 charging standard is being used by all plug-in vehicles marketed in the U.S., aside from Tesla. Tesla sells an adapter to allow use of J1772 EVSE. For inter-city travel, now a capability of BEVs, DC fast EVSE have not yet been standardized. EVSE manufacturers are compensating by providing multiple connectors to serve two or three of the competing standards.

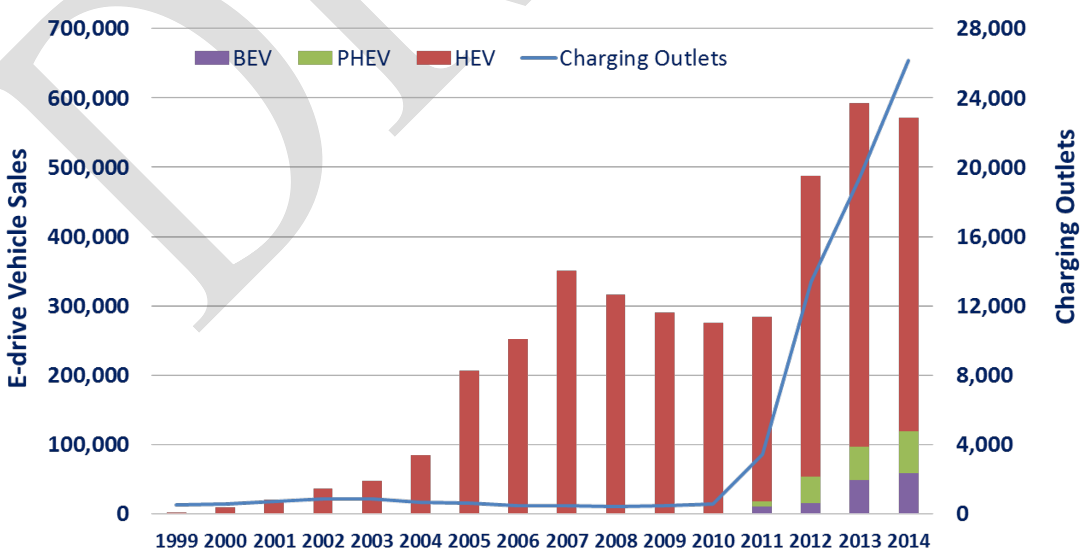


Fig. 4. Growth of annual sales of electric drive vehicles and plug-in charge points, 1999-2014

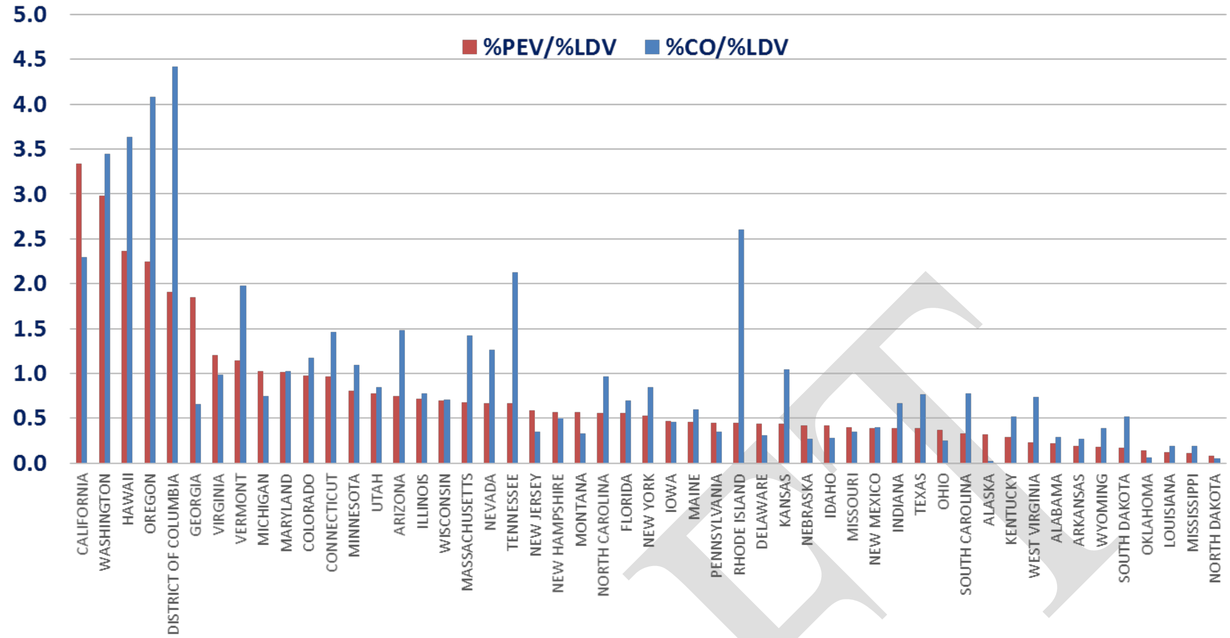


Fig. 5. Ordering of states from highest to lowest share of PEVs, with share of charge outlets adjacent

4.3 Residential Charging

Residential charge points on average have the lowest potential cost when existing plugs are available and sufficient and level 1 portable EVSE that come with the vehicle can be used. The power levels of these EVSEs ranges from 1-1.4 kW. Installation of higher power circuits for Level 2 can cost $1000-2500 for cases where consumers choose to install. Light duty BEVs in 2015 are most frequently designed to use level 2 EVSE at 6.6 and 7 kW. In the EV Project, permit costs varied from $200-$800. The amount of time actually charging is far below the amount of time connected. Less than 1 kWh has been charged per hour of residential connection time, indicating that even 8 amp 120 V charging (0.96 kW) service to the 10.5 kWh (useable) Chevrolet Volt battery pack should be adequate (on average) in most residential locations for overnight charging.

In summary, PHEVs charge at lower power levels than BEVs. Accordingly, PHEVs can be served at considerably lower residential infrastructure cost than BEVs. The 11 hour typical duration of overnight residential plug attachment will allow passenger car PHEVs with 10-50 miles of range to charge with level 1 charging equipment that comes with the vehicle. Many BEVs are now being sold with 6-7 kW level 2 charging standard, which can exceed the peak capability of many typical houses (Maitra, 2010). This may not be a problem for the first wave of BEVs, which are being sold to well educated, high income consumers that may own houses with significantly greater electrical capacity than in average houses. However, it could be a barrier to mass success of BEVs in middle income households, and to resale of BEVs to low income households.

4.4 Workplace and Other Public Charging.

Within the 2001 National Household Transportation Survey, out of the sampled cars less than 10 years old driven in Metropolitan Statistical Areas on weekdays, 56% were driven to work on workdays. For trucks the total was 61%. This implies that over half of new light duty vehicles are used for travel to and from work. These numbers are less than found for PEV owners in California, where the overall (not workday) average use for commuting was 58%. Either result implies that charging at work could serve a very large fraction of limited range PHEVs, significantly increasing their electric miles. Analyses of patterns of work trip travel and its frequency relative to other travel suggests a maximum increase of electrifiable miles of about 50% for the present Volt (Smart and Francfort, 2015). Although a near doubling is possible on workdays, vehicles are not driven to work as often as they are driven. Moreover, the distance to work is generally less than half the total day's distance, so full battery pack depletion will often not occur by workplace arrival (Santini, Zhou and Vyas).

A key long-term question is whether PHEVs with 20-30 miles of range using workplace charging will be a less expensive way of nationally electrifying miles than purchase of BEVs, EREVs, and gasoline-engine-equipped range-extended BEVs (BEVx) with less need for every workday workplace charging. Due to effects of battery mass, the larger the electrical range of available PHEV, EREV, or BEVx vehicles, the lower the highway fuel efficiency. Thus, a "hidden" benefit of workplace charging of PHEVs with 20-30 miles of range is that their intercity travel will be more efficient than for EREVs or BEVx alternatives.

Public EVSE is seldom designed for low power level 1. Early workplace charging also appears to be oriented toward level 2 rather than level 1, but information is often California based, where BEVs are most desired (Calstart, 2013). Electricity provided at such charge points is simply too cheap to meter. Some have argued that level 1 charge points with assigned parking should be preferred at workplaces when free charging is preferred, in order to minimize charging management issues. This would not work for BEV owners who arrived at work with a nearly empty battery pack, nor for BEV owners living in multi-family buildings with no charging who therefore wished to charge at work. Calstart (2013) mentions a strategy of assigning allowable time at EVSE based on the workplace commute distance. Santini, Zhou and Vyas (2012) examination of driving patterns on workdays imply that it is necessary to account for all pre-work-arrival driving, not just the commute. Errands are often done before driving to work. Calstart (2013) has said that "it is crucial … to keep the process as inexpensive and simple as possible, both for the employer and the for the end-user employees.

The Department of Energy's recent Workplace Charging Challenge Progress Update (2014) provided information that

> Employers that provide workplace charging must decide if and how employees will pay for charging station use. Many existing workplace charging programs are free for employees. In fact, 80% of employers who responded to DOE's 2014 Workplace Charging Challenge Annual Survey (2014) provided free charging access. The remaining 20% required employees to pay a fee based on usage such as electricity or time (15%) or employees paid a fixed fee (5%).

The level 2 SAE standard technically allows as much as 19.2 kW. Such EVSE would be used for truck or bus fleet operations.

DC Fast Charging is intended primarily to enable fast charging of BEVs on trips between cities. Tesla, Japanese automakers, and other automakers all adopted different DC Fast EVSE designs, leading again to incompatibility across BEVs. No EREVs or PHEVs currently include such equipment, instead relying on gasoline for intercity travel. This is being resolved by providers of DC Fast EVSE by manufacturing chargers with two or three different outlets capable of serving each class of BEV. Generally BEVs require much more expensive EVSE and EVSE installation (Smart and Francfort, 2015) than do EREVs and PHEVs. The DC fast capability is not available in all BEVs, and is usually an extra cost option when it is.

A major question is whether the lack of availability of fast, powerful public charging, or inconvenience of finding EVSE, will cause owners of BEVs to choose another vehicle when making long trips. In the EV project, the Volts were driven considerably more annual miles than the Leafs. Maximum daily distances were: Leaf - 228 mi; Volt, 1059 mi. The Volts were driven nearly as many all-electric miles (EVProject 2014). The useable kWh in the Volt pack was less than half that in the Leaf, so the accomplishment of nearly the same electrified miles must have been due in significant part to the Volt being taken on longer trips where it first ran on electricity, then on gasoline. By taking trips that were dropped by Leaf owners, and by charging more often, Volts built up significant overall electrified miles.

4.5 Infrastructure Planning

Retrofit vs. New Construction: Examination of costs of installing EVSE have taught that (1) retrofitting is far more costly than planning for adjacent parking and plugs in new construction and (2) retrofitting existing parking spots is far easier at single family dwelling units with garages and carports than in multi-family buildings with parking spots remote from dwelling units and buildings (Rubin, 2013, Frades, 2014). The difficulty of retrofitting multi-family buildings within center cities of major metro areas is a clear impediment to the BEV as a "city car". For new construction, however, a much higher percentage of dwelling units come with garages or carports than are found in the existing housing stock.

Local everyday travel: For intra-metro driving both PHEVs and all-electric vehicles (AEVs) can benefit from Level 1 or 2 daytime AC charging opportunities at the workplace, the house, or other locations. Tal. G (2014) found out that Leaf drivers and "other" car drivers which are mostly BEVs have a lower commute frequency than PHEV drivers in a California travel survey study. Tal and Nicholas found that more than 70% of sampled California PEVs were used at some time for commuting, while 58% of the PEVs were commuting on an average day. In the California sample, 83% of charging of PHEVs occurred at home, while 86% of BEVs were charged at home. These figures are likely higher than would be the case if workplace charging were widely available. Of those relatively few vehicles that did have access to workplace charging in the EV Project (Smart, 2014), Volts charged at work slightly more than at home on workdays (free charging was common), while Nissan Leafs charged at work about 42 % of the time on workdays. Public charging of both Leafs and Volts with workplace charging was only 2% on workdays, but on weekends it rose to 8% and 11% respectively. Tal et al found that the Plug-in Prius, which has only about 11 miles of charge depleting range, was charged relatively infrequently. Information on PHEVs with 20-30 miles of range remains to be collected. Such PHEVs should benefit most from workplace charging. Average daily driving of vehicles intensively used to commute to work in Atlanta was 45 miles (Santini et al, 2014). This implies that PHEVs with 20-30 miles of range would benefit significantly from workplace charging.

Intermittent long distance travel: For residential, workplace, and some fleet charging, AC Level 1 or 2 can cost-effectively accommodate charging needs. For public charging, at stations on highways between metro areas, faster charging stations are needed to deliver significant charges within typical travel schedules (Frades, 2014). A need for occasional long distance travel could make potential BEV consumers switch to other powertrains. Both the EV Project (2014a) and California research (Tal and Nicholas, 2013; Tal et al, 2014) indicate that Nissan Leafs are driven about 25% less miles than Chevrolet Volts. The influence of need for long-distance travel on BEV vs. PHEV/EREV choice is a very important consumer information consideration. Both the Electric Drive Cost Calculator (www.afdc.energy.gov/calc/) and My Plug-in Hybrid Calculator (www.fueleconomy.gov) take fuel efficiency differences involved in long distance travel into consideration when guiding consumers to estimate fuel saving. However, the Electric Drive Calculator does not ask the person using the calculator whether they place a value on time lost from frequent, time consuming BEV refueling, or on the possible need to travel off the intended path to locate a fast charging EVSE. For the My Plug-in Hybrid Calculator this question is irrelevant, since the calculator only applies to PHEVs, which use gasoline for intercity travel. The fueleconomy.gov website does not include a BEV cost calculator, nor a computational tool designed to compare BEVs to PHEVs.

5. Vehicle and Fuel Incentives and Policies

5.1 Federal Support of Plug-in Electric Drive

The expansion of HEV sales was supported by federal subsidies introduced in the Energy Policy Act of 2005. These subsidies were in force until 2010. There was a built in subsidy phase out after a specified volume of HEV sales was reached by each HEV manufacturer. Toyota exhausted its available subsidies well before any other manufacturer. These subsidies were successful, in the sense that the HEV technology remained in the marketplace after the subsidies ended.

Out of concerns arising from several years of steadily rising oil prices, along with evidence of technical and long-term commercial viability, the U.S. Federal Government decided to subsidize battery electric drive, developing a subsidy formula in the American Recovery and Reinvestment Act of 2009 that required a plug-in vehicle (PHEV or BEV) to have a battery pack of at least 4 kWh of energy storage capacity to earn a subsidy of $2500. The formula provides greater subsidy for each added kWh, up to 16 kWh, which is the nominal energy storage capability of the battery pack in the first generation Chevrolet Volt. This garners a maximum Federal subsidy of $7500. Note that the "useable" capacity (the amount of kWh that can actually be put into the pack) of a battery pack is less than its nominal capacity used to determine subsidies.

Federal support for introduction of plug-in vehicles was not confined to subsidy of battery packs. In 2011 sixteen Clean Cities Community Readiness and Planning for Plug-In Electric Vehicles and Charging Infrastructure awards were granted, totaling about $8.5 million. These were designed to help communities, states and/or regions forge public and private partnerships to plan for and develop strategies to support the adoption of plug-in electric vehicles and the corresponding charging infrastructure. The reports from the 18 month grants were completed in the spring of 2013. In this paper we extend a recent evaluation of state incentives on the 2013 state-by-state sales patterns of BEVs and PHEVs (Jin, Searle, and Lutsey, 2014). We add consideration of the effects of the "PEV Readiness" grants and climate on the 2013 state sales mixes.

Another supporting Federal effort was the "EV Project" (EV Project, 2014; Smart, 2014; Smart and White, 2014, Smart and Francfort, 2015), funded at a total of about $115 million, with matching private sector support of another $115 million. This project started in Aug. 2009. Funding of residential EVSE installation ended in March 2013. 22 participating cities or regions were served, in a total of 10 states and the District of Columbia. The majority of vehicles in this project were Nissan Leafs, while Volts also made up a large fraction. Most of the charging units installed were level 2 residential units requiring installation of higher power circuits such as those used for clothes dryers. Public level 2 and DC (Direct Current) Fast chargers for the Leafs were also installed.

In summary, the introduction of nationally and internationally marketed plug-in vehicles such as the Nissan Leaf, Tesla Model S, and Chevrolet Volt, along with compliance BEVs for California, set a technical basis for success. Federal and state incentives, and planning and organization promoted by the PEV Readiness grants also contributed to the plug-in vehicle success illustrated in Fig. 1, as did EV Project support of infrastructure installation.

5.2 Effect of State and Federal Support

It has been noted that several states have adopted various incentives to promote plug-in vehicles. Types of incentives and states that have adopted them are shown in Table 3. The 2013 effectiveness of state incentives were analyzed by Jin, Searle and Lutsey (2014). They stated that "A stepwise regression analysis shows that the most effective incentives are subsidies, carpool lane access, and emissions testing exemptions initiatives." Their estimate of total monetary benefit, taking multiple incentives into account positively correlated with BEV sales, but not PHEV sales.

As far as incentives effects are concerned, we examined the effect only of financial incentives in 2013, using the list of states that Jin et. al. had provided dollar values for. However, in our simpler statistical analysis we added a test of the effectiveness of the PEV Readiness Grants. In our case the statistical analysis was a simple yes/no (1,0) sequential test first for two groups, then four. We first grouped the 12 underlined states (and DC) in Table 1 into one test group and compared them to the remaining 39 states using t-tests for differences between a pair of unequal group means, with a one tail test. At the 5% level of significance the incentives statistically significantly increased both the share of PEVs sold and the PEVs sold per capita. When we compared the two groups with and without PEV Readiness Grants the increase in share for the Grant effect was also statistically significant, with even greater probability.

We then broke the two groups into subparts for those states that had a PEV readiness grant and those that did not. Within the states with incentives, the PEV Readiness Grants had no significant effect. The direction of the effect was positive. However, within the states without incentives, the differences were larger and the PEV Readiness Grants had a strongly significant positive effect. The group means for PEV share of light duty vehicles are illustrated in Fig. 6.

Table 3 State and Private Incentives Summary

Incentives	State
PEV Purchase Incentives: Tax Credits and Rebates	California, Colorado, DC, Georgia, Illinois, Louisiana, Maryland, New Jersey, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Washington, West Virginia*
High Occupancy Vehicle Lane Exemption	Arizona, California, Colorado, Florida, Georgia, Hawaii, Maryland, New Jersey, New York, North Carolina, Tennessee, Utah, Virginia
Lower Electric Rates for Residents with Separate Meter for PEV Charging	Alabama, Arizona, Georgia, Hawaii, Indiana, Kansas, Michigan, Minnesota, Nevada, Virginia
Charging Equipment/Installation Incentive	Arizona, California, Colorado, Illinois, Indiana, Maryland, Michigan, Tennessee, Texas,
Vehicle Inspection/Emission Testing Exemption	Idaho, Michigan, Missouri, Nevada, North Carolina, Virginia
Parking Incentives	Arizona, Connecticut, Hawaii, Nevada
Sales Tax Exemption	New Jersey, Washington
Fuel Tax Exemption	Wisconsin, Utah
Reduced License and/or Use Tax	Arizona, Washington
Reduced Registration Fee	Illinois, Iowa
Conversion Tax Credit	Montana
Vehicle-to-Grid Energy Credit	Delaware
Idle Reduction Technology Tax Credit	Colorado
Weight Limit Exemption	Colorado
Title Tax Exemption	District of Columbia
Reduced Toll Road Rates	New Jersey

Underlined states had $ values for incentives in 2013 according to Jin, Searle and Lutsey (2014).

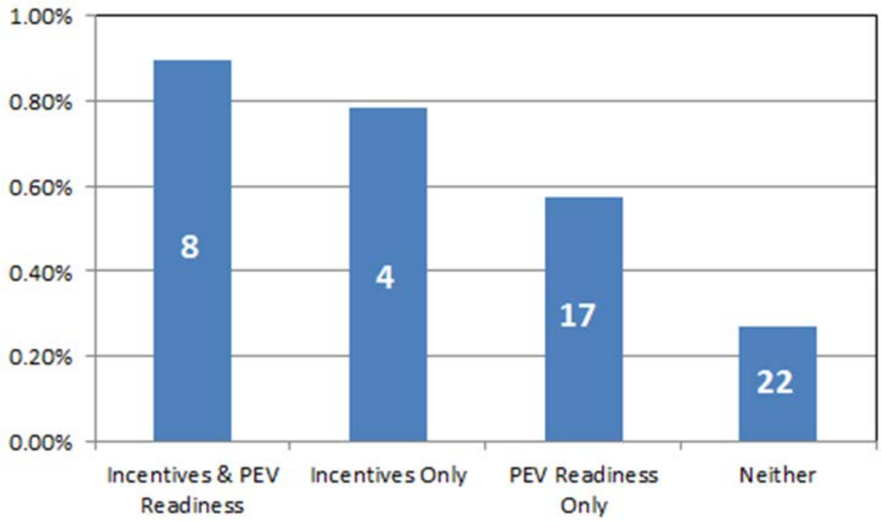


Fig. 6 PEV share of light duty vehicles registered in 2013 vs. incentives and/or PEV Readiness Grants (number of states and DC shown in bars)

This experiment led us to wonder if there might be a compositional effect, particularly in light of the Jin, Searle and Lutsey finding that the estimated value of all incentives affected BEVs but not PHEVs. Further, we wondered if climate would have a compositional effect, reducing the share of BEVs sold in cold climate states. The average group values for the tests are shown in Fig. 7.

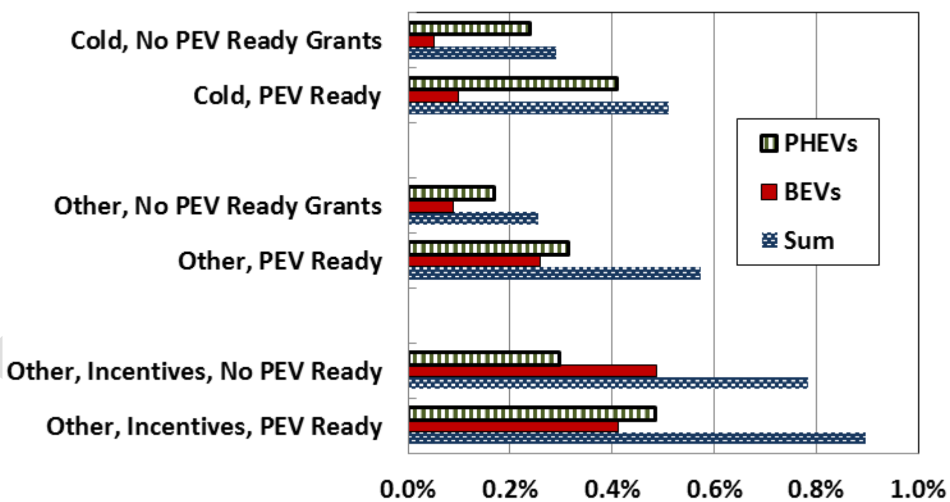


Fig. 7 Group Mean Share of 2013 State Light Vehicle Registrations

In the 14 cold states (shown later in Fig.8) statistical tests indicated significant effects of PEV Readiness Grants on total PEVs, BEVs and PHEVs. In other states without incentives, the share of PEVs in total and of PHEVs was also significantly increased. BEV differences were also positive and nearly significant. As before, there were no statistically significant effects of PEV Readiness Grants when incentives existed. Of course, some PEV Readiness Grants might have increased the support for incentives, or those already implementing incentives may have been more able to successfully seek Grants — topics for more detailed case study.

In summary, after accounting for the cold state climate effects (discussed later in Section 7.1), we found that the the PEV Readiness Grants alone were effective. They were effective in the majority of states where they were used. It is not at this time clear which of the strategies promoted by PEV readiness grants have been most effective. However, a summary of strategies, with links to the plans where those strategies were evaluated and developed, should be a valuable resource (http://www.afdc.energy.gov/uploads/publication/guide_ev_projects.pdf) . Quarterly webinars are highlighting important strategies.

As Fig. 6 illustrates, the share of PHEVs registered was relatively constant across groups, but the share of BEVs varied considerably. For the states without incentives, the differences in share of BEVs within PEVs was significantly less in the cold states than in the other states, holding the PEV Readiness Grant effect constant. This implies that cold temperatures significantly reduce the marketability of BEVs. The PEV Readiness Grants had no significant effect on the proportion of BEVs. The incentives had a strong positive effect on share of BEVs only when compared to cold states. Thus, it appears that the deterrent effect of cold temperature is a significant problem.

Of the cold states, two in the Northeast were signatories of the eight-state MOU. The BEV share of the Northeastern six of the eight states signing the MOU were significantly less (30%) than for California and Oregon, treated as a group (54%). Cold weather may play a role in this difference. California regulations allow the next few years of ZEV vehicles to be as much as 50% BEVx vehicles such as the BMW i3 REX. The fact that 70% of the Northeastern states PEVs are PHEVs may indicate that Northeastern customers might want a larger share of BEVx vehicles than the regulation allows. Tracking the sales mix of BMW i3 REX vs. BEVs in the Northeast vs. the West Coast may help provide guidance on the difficulty of attaining the ZEV goal of at least 50% pure BEVs in the Northeast.

5.3 Air Quality Considerations.

Despite decades of progress on reducing emissions from vehicles, California still has several areas out of attainment of the Clean Air Act standards. Los Angeles has average ozone concentrations higher than any other U.S. metro area. Ozone standards may be tightened in the future. As a result California has long been allowed to set more strict emissions standards that the rest of the U.S. Over time, other states sought the right to use California standards instead of the Federal standards. These efforts were resisted by the auto industry via lawsuits. Nevertheless, the right for other states to make use of California standards was granted by the U.S. Environmental Protection Agency in recent years (http://www.epa.gov/otaq/cafr.htm#state). Nine other states now follow California's ZEV program for passenger cars and light duty trucks. Eight of the 10 states in the ZEV program recently signed a memorandum of understanding (MOU) to cooperate in efforts to introduce plug-in vehicles. The follow-up MOU "Action Plan" states that BEVs, PHEVs and FCVs can be part of manufacturers' strategy for meeting plan goals (Solomon, 2014). Of the eight states, two are on the West Coast (California and Oregon) while those remaining are in the Northeastern U.S. with much colder climates.

Those metro areas that wish to have guaranteed ZEV operation may prefer BEVs and perhaps EREV and/or BEVx PEVs to PHEVs. Atlanta is a metro area with air quality nonattainment problems. Unlike most states that have chosen to subsidize both BEVs and PHEVs (like the Federal Government) Georgia has chosen to only subsidize BEVs, with a generous \$5000 subsidy. The BMW i3 REX BEVx and Volt EREV do not qualify. The intent is zero emissions. Three FCVs also qualify. Sales and use tax exemptions are available to dedicated Alternative Fuel Vehicles in Washington State – thus BEVs but not PHEVs. The Washington State exemptions do not relate to a ZEV goal.

The majority of the population in the U.S. live in areas that do meet air quality standards. Generally, EREVs and PHEVs have lower tailpipe emissions than the average light duty vehicle. Reduction of greenhouse gas (GHG) emissions is a worldwide and nationwide goal, while reduction of oil imports is a nationwide goal. Accordingly, for these purposes nationwide subsidies of any plug-in vehicle that can increase electrified miles is logical, though there remain questions about GHG, particulate and sulfur oxide (SO_x) effects in some locations under charging strategies that result in coal providing a large share of the electricity generated. Studies of the net upstream emissions effects from charging BEVs, EREVs and PHEVs show that results can vary considerably, depending on the electrical grid mix in the location that charging occurs, and the hours of the day that charging takes place. "Smart grid" and "time-of-use" (TOU) electric rate advocates have been encouraging charging at night when power generation needs are lowest. Unfortunately, in many areas this causes the charging to be provided by coal fired power plants, which can negate GHG, particulate and SO_x emissions benefits. However, charging on the shoulders (late evening or early morning) of the overnight load trough can shift the charging mix considerably, reducing the contribution from coal and shifting it to clean natural gas or, in some locations, wind. Further, the share of coal used in electricity generation is steadily declining and old dirty coal power plants are either being decommissioned or upgraded. Best charging practices are under development. Southern California Edison (2013) has studied the options and recommends charging in early morning hours so that the battery is full just before the intended departure time. This tends to be clean and to efficiently use existing generation capacity. Unfortunately, most research evaluations of charging strategies have so far neglected to examine this charging strategy. EV Project (2013a) information does imply that this strategy is not presently being followed by consumers. Accordingly, promotion of this behavior will be necessary in the future, where research for areas of the nation other than California confirms that it is more desirable than the usual evening charging (TOU rates absent) or nighttime charging (TOU rates present).

6. Current Clean Cities Activities

Several existing national Clean Cities activities are being updated or enhanced addressing the electric-drive vehicle market barriers or showcasing opportunities.

6.1 Communication Products

AFDC and Clean Cities
Websites: http://www.afdc.energy.gov/fuels/electricity.html; www.cleancities.energy.gov A variety of tools, publications, and information are provided on these sites, such as the Vehicle Cost Calculator, Alternative Fuel and Advance Vehicle Search, and Laws and Incentives Database. YouTube postings on the Clean Cities website feature local Clean Cities success stories and training videos for contractors and inspectors for EVSE.
MotorWeek Series: www.youtube.com/cleancitiestv For more than 10 years, Clean Cities has had a relationship with MotorWeek which produces a series of Clean Cities success stories and feature-length segments for public television.
Handbooks: Plug-in Electric Vehicle Handbooks were developed for several topics: Workplace Charging Hosts, Fleet Managers, Electrical Contractors, Consumers, Public Charging Hosts, with the latest being created for Multi-Unit Dwellings. See the latest on Multi-Unit Dwellings at http://www.afdc.energy.gov/fuels/electricity_charging_multi.html
PEV Quarterly Webinar Series: http://www.afdc.energy.gov/cleancities/webinars/#/past
Since 2010, Clean Cities has been offering PEV related webinars for Clean Cities stakeholders.

6.2 Partnerships

National Clean Fleets Partnership:
www.eere.energy.gov/cleancities/national_partnership.html Some of the nearly 30 national partner fleets use electric-drive vehicles, primarily for short-haul delivery. Fleets receive specialized resources, expertise, and support to incorporate alternative fuels and advanced vehicles into their operations and share lessons learned with the Clean Cities network. Frito-Lay, one of the national partners, is a prime example of using battery electric vehicles for dense urban routes.
National Parks Initiative:
Clean Cities works with the National Parks Service (NPS) to help educate visitors to the parks about the importance of petroleum reduction in the transportation sector through the use of alternative fuels, advanced vehicle technologies, and petroleum reduction practices. Shenandoah is an example of a park

fleet using electric drive vehicles. http://www1.eere.energy.gov/cleancities/national_parks.html#shenandoah

In celebration of its 100th Anniversary, the National Park Service wants to expand EVSE at 100 National Park sites as part of its "Driving Towards Sustainability" initiative, presenting another partnership opportunity for Clean Cities.

National Governors Association: http://www.nga.org/cms/home/nga-center-for-best-practices/meeting--webcast-materials/page-eet-meetings-webcasts/col2-content/main-content-list/state-and-local-plug-in-electric.html The National Governors Association has worked with Clean Cities to offer two workshops for coordinators and state energy staff on PEV policy and technology. These limited attendance workshops offer coordinators and states the ability to interact to share lessons learned and develop future ideas for greater deployment in their states. Plans in 2015 include working with PEV organizations to provide targeted policy or technical training.

Workplace Charging Challenge: http://energy.gov/eere/vehicles/ev-everywhere-workplace-charging-challenge

Clean Cities coalitions work with the Challenge to sponsor employer workplace meetings and identify potential employers wanting to take the pledge to install EVSE at their worksites.

6.3 Technical Assistance

Clean Cities University: http://www1.eere.energy.gov/cleancities/toolbox/university.html This is an online training tool for Clean Cities coordinators that can be expanded. In addition to a current course on "Electric Drive Vehicles: Overview and Impacts" content could be developed on understanding site development, items to consider for workplace charging programs, and understanding which battery types are best suited for urban, suburban, rural populations and weather, etc.

Technology Bulletins and Reports: http://www.afdc.energy.gov/uploads/publication/guide_ev_projects.pdf "A Guide to the Lessons Learned from the Clean Cities Community Electric Vehicle Readiness Projects" was developed capturing the experiences of 16 awardees of the EV Readiness Projects. Each awardee also has developed numerous community readiness roadmaps and reports ranging from American Disabilities Act compliance to taxation and are posted at http://www1.eere.energy.gov/cleancities/electric_vehicle_projects.html

Training on EVSE Residential Charging Installation: http://www1.eere.energy.gov/cleancities/evitp.html In partnership with the Electric Vehicle Infrastructure Training program, a training video was developed helping electric contractors and inspectors learn safety, technical, and consumer issues before installing charging equipment in residential and commercial markets.

Training for First Responders: http://evsafetytraining.org Since 2009 Clean Cities and other areas of the Office of Vehicle Technologies have funded training for first responders. Clean Cities coalitions help to organize and generate the appropriate attendee lists to these workshops, with generated content from expert organizations, such as the National Fire Protection Association and the National Alternative Fuels Training Consortium.

6.4 Tools

AFDC Station Locator: http://www.afdc.energy.gov/locator/stations/ Various data have been recently added to the Fueling Station Locator for PEVs, such as Charger type – the type of electric chargers available at the station (e.g., Level 1, Level 2, DC Fast, Legacy chargers); Connectors and outlets – the type of outlets (e.g., NEMA 14-50, NEMA 5-15, NEMA 5-20)and connectors (e.g., J1772, CHAdeMO, J1772 Combo, Tesla) available for charging; and Networks – the name of the EVSE network.

AFLEET Tool: https://greet.es.anl.gov/afleet Stakeholders have asked for more vehicle types to be included in AFLEET, an Alternative Fuel Life-Cycle Environmental and Economic Transportation Tool. In FY 2015, EVSE will be added.

PREP Tool: http://www.afdc.energy.gov/prep/ The Petroleum Reduction Planning Tool helps a vehicle fleet reduce petroleum consumption and greenhouse gas (GHG) emissions. A comprehensive plan can be created for a fleet by using several savings methods.

My Plug-in Hybrid Calculator: http://www.fueleconomy.gov/feg/Find.do?action=phev1Prompt This calculator can help estimate personalized fuel use and costs for a plug-in hybrid based your driving habits, fuel prices, and charging schedule.

PEV Readiness Scorecard: https://www.afdc.energy.gov/pev-readiness The Plug-In Electric Vehicle Readiness Scorecard helps communities assess their readiness for the arrival of PEVs and EVSE. The tool offers feedback on steps that could be taken for increasing readiness and tracks progress.

Permit Template: http://www.afdc.energy.gov/pdfs/EV_charging_template.pdf This template is useful in developing a standard permit for residential charging stations that allows for quick, safe installation of EVSE.

7. Patterns

7.1 Climate.

Evidence of the negative effect of cold weather on BEV range is receiving attention (Allen, 2014, Fleet Carma, 2014, Lohse-Busch, 2012, Rosack, 2015, Santini, 2014, Yuksel and Michalek, 2015). The Volt Stats! website (Rosack), which includes an option to plot monthly mpg, shows a 14% drop in Volt electric drive "mpg equivalent" from the best month (September) to worst (January), on a national average basis. Allen and Fleet Karma show that range declines as great as 50% (relative to results in fall or spring) are possible for BEVs when temperatures are well below freezing. Yuksel and Michalek generated estimates of Nissan Leaf temperature effects nationwide, creating a "heat map" of estimated average annual Wh/km. Worst cases relative to moderate Pacific coast and Southeastern U.S. locations were found in cold northern tier states and hot southwestern desert locations. Variation of about 20% was estimated. The West Coast, near the Pacific was one of the most favorable locations for the Leaf, as was Hawaii. The apparent favorability of the West Coast and Hawaii is shown in Fig. 8, which plots BEVs per capita, by state. The effect of the generous subsidies of BEVs in Georgia shows up on the map. It is also true that Georgia is a good location according to Yuksel and Michalek. Coldest day drops for a BEV in a snowstorm in a cold state are the worst case (Santini, 2014). This case may be worse than any of the above analyses have estimated, since driving in a snowstorm was not examined.

Using the aforementioned heat map (Yuksel and Michalek), 14 of the coldest states were isolated to see if cold weather range penalties appear to reduce the share of BEVs sold in a state. Assessment complications arise because the EV Project, which promoted the leading selling BEV, had no participating states among the fourteen. Thus, a lower proportion of BEVs in the cold states could be due to a lack of subsidy of infrastructure. On the other hand, the absence of participation of those states could also be due to an understanding that BEVs are not as attractive an option in particularly cold climates with relatively low population density often requiring relatively long distance travel to meet everyday needs. It was also true that none of the states providing financial subsidies were among the 14 coldest states.

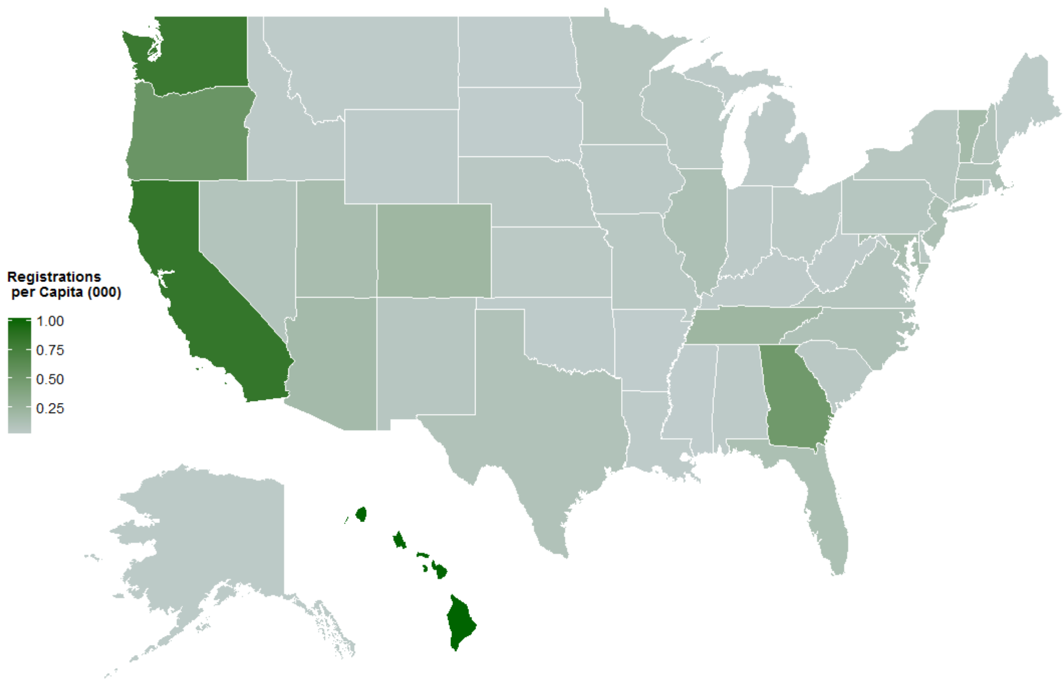


Fig. 8 Battery electric vehicles per capita
(based on registrations as of April 2014, provided by National Renewable Energy Laboratory).
Cold states: ID, MT, WY, ND, SD, NB, WI, IA, MI, MN, NY, VT, NH, ME

7.2 Spatial Patterns of Likely Best Use of Various PEVs.

German PHEVs, which have initially been introduced in luxury vehicles, have been designed with the idea that they will be owned by high income households living in suburbs but working in downtown areas that were anticipated to adopt zero emissions zones (Santini, 2014). The vehicles have an option to use the gasoline engine to charge the battery to allow zero emissions driving in zones with such restrictions. Such zones have not materialized. The Chevrolet Volt has a “hold” option which allows choice of HEV mode first, then all electric operation later. This was motivated by European PHEV design priorities, so that the powertrain could be used in the German Opel Ampera.

Santini and Zhou (2015) have illustrated the unsurprising result that BEVs save the most money per day when driven close to their full range. They also illustrated that when holding number of hours per day constant, savings for some HEVs and PHEVs could be larger if driven less distance at lower average speed. In contrast, for the same daily hours of operation, BEV savings consistently increased with average speed. Thus, the theoretical advantage of the BEV over some PHEVs becomes large if the range considerably exceeds the AER of the competing PHEV, and that range is used routinely. Unfortunately, in a cold climate, purchasing a BEV to match the summer driving range can lead to failure to meet the day’s needs in the winter. Further, as BEVs age, they gradually lose battery capacity, so the prospective owner must take that into account. Were new construction of single family houses to revive at the edge of metro areas due to lower gasoline prices, BEV purchasers in areas with cold snaps would have to take care to purchase a range reserve. The BMW i3 REX (BEVx) or coming 2015 model year 50 mile AER Volt EREV could address this problem. While new construction in low density suburbs cannot lead to rapid market penetration of PEVs, since only about 2% of houses are replaced each year, it nevertheless has the defensive attribute of being potentially low cost with respect to EVSE and advantageous on a per vehicle basis, by normally exhausting the AER of the vehicle, helping pay off the added costs with high daily operations savings. A defensive, low cost strategy for preservation of the PEV market may be necessary if oil and gasoline prices remain low.

Another potential opportunity might be near suburbs undergoing housing replacement via tear-downs of existing homes and replacement with larger new homes by upper income households choosing to move closer to work opportunities. This subgroup might be a target for Tesla customers. However, so far, the average income of purchasers of plug-in vehicles has been quite high, so the subgroup might be a target for PEVs generally (Tal and Nicholas, 2013; EV Project, 2013b).

Still another consideration is resale. Since most PEVs are being sold to high income households, they are likely going into modern homes with high capacity electrical systems incorporating air conditioning and many electrical appliances and devices. This probably will not be the case when the first wave of PEVs enters the used car market. Success in selling into this market is desirable on two grounds. First, the more years and electric miles of use obtained, the more oil saved and tailpipe emissions reduced. Second, the higher the resale value of used PEVs, the lower the cost of lease of new PEVs will be in the future. Thus, it is desirable to think about how well matched the charging strategy will be to the housing stock of second owners.

Peak electrical loads in many existing dwelling units are well below the standard 6.6-7 kW charging power being designed into BEVs (Maitra, 2010). Thus, standard BEV charging could overload electrical systems of many existing dwellings. PHEVs, having smaller battery packs have been designed with lower power chargers to save money and because such chargers are more than adequate to fill the pack each night. Thus, PHEVs are less likely to overload residential electrical systems. The cost to the consumer is the need to plug in much more frequently than with a BEV. PHEVs must be charged before nearly every day of use. They can be charged at a "level 1" rate of 1-2 kW and easily fill the pack overnight (though this is not necessarily true for a Volt at 1 kW). Such charging is probably acceptable in the majority of older dwellings. BEVs can also be partially charged every day like PHEVs, with what is termed the "trickle charger". It may be desirable to de-emphasize the importance of fast residential charging when providing information for potential purchasers of used BEVs.

7.3 Varying Model Attributes

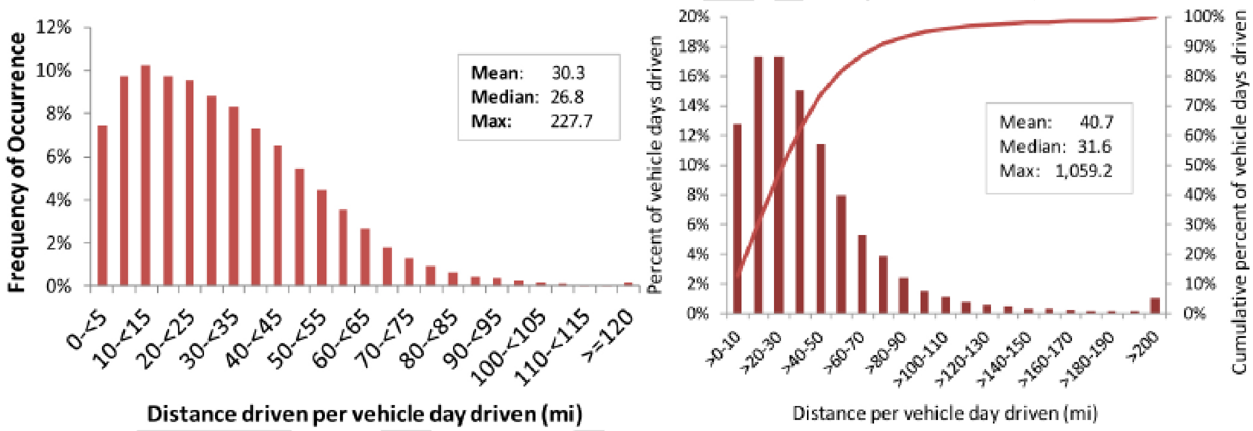
Today, along with many new BEVs introduced to meet CARB ZEV regulations, there are multiple PHEVs designed to take advantage of the regulation's 10 mile (minimum) PHEV AER credits, including the Plug-in Prius and the Honda Accord PHEV. 2015 model BEVs designed almost exclusively to meet the CARB ZEV regulation are termed "compliance cars", which are all available in California. Otherwise availability in other states is very limited. Compliance BEVs and the Nissan Leaf are considerably more efficient in city operation than in highway operation. The Tesla Model S, however, is more efficient in highway operation than in city operation. With its greater range, the Tesla is suitable for owners in wealthy suburbs who drive further and faster than city residents. The Chevrolet Volt also has the property that highway operation is more efficient than city operation, as do recently introduced Porsche PHEVs. The Plug-in Prius and Ford Energi systems, which are modified HEVs, do not. Such differences have a bearing on the best PEV location within a metro area for particular plug-in technology. In California, it has been observed that BEVs make up a higher share in core cities, while PHEV share is higher in suburbs (Tal and Nicholas, 2013).

The most important feature of the PHEV is whether it has all-electric range, and if so, how far that range is. The Plug-in Prius' official EPA rating indicates it uses gasoline and electricity. This is also true for the Porsche Panamera PHEV, though not the Cayenne PHEV. The Honda Accord and Ford Energi PHEVs are reported to use trace amounts of gasoline. These are each "type b" vehicles in our classification scheme. The Volt (type c) and BMW i3 REX (type d) do not use any gasoline when charge depleting. The 2014 Volt and BMW i3 REX (gasoline assist) have ranges of 38 and 72 miles respectively. All other type b PHEVs have ranges from 11 (Prius) to 20 (Energi) miles. For PHEVs in the latter group, workplace charging everyday could be very advantageous. The Volt, particularly the coming version anticipated to have 50 miles of range, and the BMW i3 REX would probably seldom need workplace charging if they could be charged at home at a lower cost than at work. Free charging at work might cause them to use the workplace instead of the house.

This section illustrates that the combinations and permutations of electric drive and conventional-drive vehicle are extensive. This complicates consumer choices considerably, even without considering infrastructure complications. The dealer experience of PEV purchasers has proven to be much worse than for conventional vehicles (Morris, 2014). Thus, improvement of already extensive consumer information tools seems to be necessary for these numerous technology choices.

8. New Strategies to Eliminate Barriers

Long-term charging infrastructure deployment and complex consumer choice are the barriers that need new strategies. The EVProject shows that Leaf drivers averaged about 30 miles per driven day while Volt drivers averaged about 40 miles nationally per driven day (Fig. 9). If the new generation Volt has a charging depleting range of around 50 miles, it would theoretically satisfy over 70% of intra-urban driving (Fig. 9). Voltstats reports 75% electrified miles with Volts that have range from 35-38 miles. Table 4 summarizes suggested new strategies to eliminate barriers.



Nissan Leaf Chevrolet Volt

Fig. 9. Distribution of distance driven per vehicle day driven (EV Project, 2013 Q4)

The most obvious barrier to market success is total life cycle cost of ownership. Propfe et al (2012), using German information on rates of depreciation by PEV type, estimated that depreciation would be one of the biggest problems for PEVs, particularly BEVs. In that analysis PHEVs had lower total cost of ownership than BEVs in large part because of depreciation. This shows up for the U.S. case in a recent estimate of 5 year cost of ownership (Anderson, 2015), where three BEVs consistently had higher 5 year cost than a gasoline version or counterpart. The one PHEV and four HEV comparisons were much closer on average, with the electric drive option winning in two of the five comparisons we constructed from the data. A potential solution to this problem is being developed. If battery packs can last longer than the life of the car, and can be disassembled and repurposed for energy storage in stationary uses for the electrical grid, commercial buildings, or houses, then the resale value of BEVs could rise significantly. In a recent pre-show presentation at the Chicago auto show, William Wallace, the director of the battery pack development program for the 2015 Chevrolet Volt (and GM battery systems worldwide) said that it was now expected that the packs could last beyond the life of the vehicle. Research on storage uses was preliminary, but by the time the 2015 Volts' useful lives are over, there may well be markets for repurposed packs, increasing Volt resale and/or scrappage value. Should it become evident that this research is paying off and secondary markets are emerging, it would be appropriate to educate would be buyers about the long life and residual value of battery packs.

Table 4 Barriers and New Strategies

Barriers	New Strategies
Cost of long-term charging infrastructure deployment	Study the impacts of longer electrification range PEV models on need for intra-urban charging infrastructure. The longer the PEV range, the less frequent the use of public charging (e.g. Workplace charging) in urban areas for those models. Availability for occasional long distance BEV days could be valuable, however. Track trends in PEV type location cross-matched to type of infrastructure needed to assist spatially effective EVSE infrastructure investment choices. Track availability of infrastructure with BEV vs. PHEV sales to determine how effective building infrastructure is in enhancing sales Continue to track electric and total miles driven by BEVs, BEVx, EREV, PHEV and HEV powertrains in comparison to comparable conventional vehicles, accounting for public infrastructure benefits – particularly workplace for all PEVs and DC Fast charging for BEVs.
Complexity of consumer choice Improving consumer satisfaction at dealers and online.	Develop a user friendly App (user interface) for consumers and dealers to rank the most cost-effective electric drive models (HEV, PHEV, EREV, BEVx, BEV) for the customer's daily needs (intra-urban vs. inter-urban distances, speeds and resulting efficiency, towing capability, passenger and luggage capacity, days of overnight parking at home, etc) considering the model availability, infrastructure availability, utility electricity price, climate and terrain impacts, etc). Enhance tools at AFDC and fueleconomy.gov to enable easier comparison of models across OEMs Compare electric drive options with other available AFV and advanced vehicle models

9. Future Directions.

Electric drive is set to expand into a wider range of powertrains. The start-stop and micro HEV powertrains will provide greatest benefits in congested stop and go driving. These will automatically end light duty vehicle idling at pedestrian intersections, which should provide a very local health benefit. This is one expansion of promotional activity that Clean Cities and its coordinators can pursue.

The success of the PEV Readiness Grants suggests that the organizational efforts promoted by Clean Cities, making use of the lessons learned from these Grant Reports, should have a positive effect in other states, should Clean Cities Coordinators and affiliated stakeholders take advantage of them. The success shows that organization, planning, stakeholder coordination, legislation and regulation revisions can all have benefits in successfully making customers comfortable with purchasing plug-in technology.

A defensive strategy in the event of continued low oil prices may be to emphasize plug-in ready building codes for new construction. This is the least costly way to build residential and commercial charging infrastructure. Where these codes are created, coordinated promotion of plug-in vehicles in those communities should be pursued, as well as supporting public and workplace charging, to the extent that funds are available and/or local businesses seek to serve those households that choose plug-in vehicles as a part of their vision for the future. To the extent that such construction is in relatively low density areas, the daily driving extent and frequency of daily use of the plug-in vehicles should be financially advantageous.

While per vehicle fuel savings benefits require quantification, some ad hoc judgment is possible. Because of long BEV range and probable replacement of high performance gasoline vehicles, Tesla BEVs are likely to be driven considerably more electric miles than other plug-in vehicles, with greater fuel savings and emissions reduction per mile (Santini and Burnham, 2013). Making consumers aware of this benefit could create a "halo" effect for the technology that might generally increase sales.

Choices of time of overnight charging can be important. Researchers should provide more analyses of these trade-offs, with greater attention to the charge by departure option. When research documents benefits implied by Southern California Edison (2013) analysis in other locations, or finds different locally tailored charging time choices to be preferable, Clean Cities should promote voluntary good charging practices. Evaluations of emissions of plug-in vehicles should take into account trends toward cleaner power plants. This knowledge should emerge in the next five years.

Attention should be paid to the question of cost of adapting and installing charging infrastructure to support pure BEVs vs. do-no-harm low power, timely charging by PHEVs, EREVs and BEVx vehicles using existing electrical infrastructure to support local travel and gasoline infrastructure for long distance travel. Particular attention should be paid to this trade-off in cold climates, to better understand whether pure BEVs can be widely successful in these locations.

Cost effectiveness of workplace charging in support of more frequent charging of less expensive PHEVs with modest AER should be compared to an alteration of workplace charging design intended to occasionally provide EREVs and BEVx vehicles inexpensive electricity in support of extended evening travel after work. Finally, costs of installing DC Fast Charging networks to promote pure BEVs, particularly in and around areas out of air quality attainment, should be addressed. Comparisons to the cost of hydrogen infrastructure and other support of FCVs in such locations would also be desirable. Assessment of declines in needs for public charging as the AER of plug-in vehicles improves over time should be pursued.

The problem of promoting plug-in vehicles as used cars, to assure years of electrification of miles should receive attention in the next five years. Suitability of older residences should be examined and target "trickle down" markets considered.

Due to exploitation of a wide range of design trade-offs in plug in vehicles balancing power output from both engines and electric motors/batteries the relative financial viability of various plug-in vehicles can vary considerably. The amount of fuel savings per year across electric drive makes and models varies far more across different patterns of vehicle use than for conventional vehicles. Accordingly, there is potential for mistakes and consumer backlash if inadequate information is provided during the vehicle search phase by consumers. This represents a challenge that must be addressed, via development of even better consumer information tools than already exist, as well as focus on better use of the ones that do exist.

Acknowledgments

This work was supported by the Clean Cities Program of the Vehicle Technology Office of the Office of Energy Efficiency and Renewable Energy of the United State Department of Energy. Support is gratefully acknowledged. Judgments expressed are those of the authors, not the United State Department of Energy.

References

U.S. Energy Information Administration (2014). Annual Energy Outlook 2014, U.S. Department of Energy, Energy Information Administration, DOE/EIA-0383(2014). Washington, DC. (April). (http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf).

Alexander, D. (2015). Electric Drive Trucks and Buses: Market Data for Medium and Heavy Duty Commercial All-Electric, Plug-In Hybrid Electric, and Hybrid Electric Vehicles. Navigant Research, Chicago, IL. published online: 1Q 2015. http://www.navigantresearch.com/research/electric-drive-trucks-and-buses

Allen, M. (2014). Electric Range for the Nissan Leaf & Chevrolet Volt in Cold Weather. Fleet Carma. Waterloo, Canada. http://www.fleetcarma.com/nissan-leaf-chevrolet-volt-cold-weather-range-loss-electric-vehicle/ (released Dec. 16, 2014; accessed Feb. 19, 2015).

Calstart (2013). Best Practices for Workplace Charging. (Sept.) (http://www.calstart.org/Libraries/Publications/Best_Practices_for_Workplace_Charging.sflb.ashx)

Engeldinger , R. (2014) Washington Completes the First Fully Electrified Scenic Loop Drive Earth Island Journal (Oct. 24). (http://www.earthisland.org/journal/index.php/elist/eListRead/washington_completes_the_first_fully_electrified_scenic_loop_drive/)

EV Project (2013). Overview. (http://www.theevproject.com/overview.php)

EV Project (2014a). How many electric miles do Nissan Leafs and Chevrolet Volts in the EV Project Travel? Idaho National Laboratory Paper INL/EXT-14-32135 (May). (http://avt.inel.gov/pdf/EVProj/eVMTMay2014.pdf).

EV Project (2014b). Charging and Driving Behavior of Nissan Leaf Drivers in The EV Project with Access to Workplace Charging. Idaho National Laboratory Paper INL/EXT-14-33700 (Nov.) (http://avt.inl.gov/pdf/EVProj/WorkplaceChargingandDriving-Leaf.pdf).

EV Project (2014). Workplace Charging Frequency of Nissan Leafs and Chevrolet Volts in The EV Project at Six Work Sites. Idaho National Laboratory Paper INL/EXT-14-33701 (Nov.). (http://avt.inl.gov/pdf/EVProj/ChargingAtSixWorkSites.pdf)

EV Project (2013a). How do PEV owners respond to time-of-use rates while charging EV Project vehicles? (July) (http://avt.inl.gov/pdf/EVProj/125348-714937.pev-driver.pdf).

EV Project (2013b). Who are the participants in the EV Project? (Aug.) (http://avt.inl.gov/pdf/EVProj/128842-80098.devproj.pdf).

Fleet Carma (2012). Webinar: The Truth About Electric Vehicles (EVs) in Cold Weather. Fleet Carma, Waterloo, Canada. https://www.fleetcarma.com/resources/the-truth-about-electric-vehicles-in-cold-weather-webinar/download-164051/ (Released March 15, 2012; Accessed Feb. 19, 2015).

Frades, M. (2014). A Guide to the Lessons Learned from the Clean Cities Community Electric Vehicle Readiness Projects. U.S. Department of Energy Clean Cities Program (http://www.afdc.energy.gov/uploads/publication/guide_ev_projects.pdf) (January).

Garas, D. (2012) About PEV Consumers. Presented at the State and Local Electric and Plug-in Hybrid Vehicle Workshop: Getting Ready Together. National Governors Association, Washington DC. (http://www.nga.org/files/live/sites/NGA/files/pdf/1207EVGaras.pdf) (July 10).

Gross, B. (2014). PEV Infrastructure: Looking Back After 3 Years. SAE Government/Industry Meeting, Washington DC. (http://www.sae.org/events/pdf/gim/2014_gim_guide.pdf) (Jan. 23).

Jin, L., S. Searle and N. Lutsey (2014). Evaluation of State-Level U.S. Electric Vehicle Incentives. White Paper. International Council on Clean Transportation, Washington DC. (Oct.). (http://www.theicct.org/sites/default/files/publications/ICCT_state-EV-incentives_20141030.pdf)

Lohse-Busch, H. et al (2012). Advanced Powertrain Research Facility AVTA Nissan Leaf testing and analysis. Argonne National Laboratory (Oct. 12).

(http://www.transportation.anl.gov/D3/data/2012_nissan_leaf/AVTALeaftestinganalysis_Major%20summary101212.pdf)
Maitra, A., (2010) "Plug-in Vehicle Drive Impacts to the Grid," TRB Environment and Energy Conference, Raleigh NC, (June 7-9) (http://www.cte.ncsu.edu/eeconference/sessions/documents/06-3_Maitra.pdf).
Morris, C. (2014). The Dealership Dilemma, Are Auto Dealers the EV's Worst Enemy? Charged Electric Vehicles Magazine. Issue 14 (June/July) pp. 42-49.(http://chargedevs.com/features/are-auto-dealers-the-evs-worst-enemy/).
Nicholas, M. and G. Tal (2013). Charging for Charging: The Paradox of Free Charging and Its Detrimental Effect on the Use of Electric Vehicles. University of California at Davis Working Paper UCD-ITS-WP-13-02. (October). (http://www.sacog.org/complete-streets/toolkit/files/docs/Charging%20for%20Charging%20The%20Paradox%20of%20Free%20Charging_2013__PEV%20Resource.pdf)

National Renewable Energy Laboratory analysis, R.L. Polk, POLK_VIO_DETAIL_2013, [Feb. 2015].

Reuters (2009). UPDATE 2-US EPA approves California auto emissions standard (June 30). (http://www.reuters.com/article/2009/06/30/autos-epa-california-idUSN3044688920090630)

Rosack, M. (2015) Volt Stats! (http://www.voltstats.net/) (accessed Feb. 2015).
Rousseau, A., et al. (2012). *Comparison of Energy consumption and costs of different HEVs and PHEVs in European and American context.* Presented at the European Electric Vehicle Congress Brussels, (Nov. 19–22). (http://elib.dlr.de/80776/1/2012_EEVC_-_Comparison_of_Energy_consumption_and_costs_of_different_HEVs_and_PHEVs_in_European_and_American_context.pdf).
Rubin, B., (2013). Zero Emission Vehicles in California: Community Readiness Guidebook. Governors' Office of Planning and Research, California. Fall, First edition. (http://opr.ca.gov/docs/ZEV_Guidebook.pdf.)
Santini, D.J. (2014). Plug-in Hybrid Electric Vehicles. IA-HEV 2014 Task 15 Report. International Energy Agency Implementing Agreement on Hybrid and Electric Vehicles. (http://www.ieahev.org/assets/1/7/IA-HEVTask15ReportFinalFeb20142.pdf).
Santini et al, (2014). Daytime Charging – What is the Hierarchy of Opportunities and Customer Needs? ─ A Case Study Based on Atlanta Commute Data. TRB 14-5337. Presented at the Annual Meeting of the Transportation Research Board, Washington, DC (Jan.). (http://docs.trb.org/prp/14-5337.pdf).

Santini, D.J., and A.J. Burnham (2013). Reducing Light Duty Vehicle Fuel Consumption and Greenhouse Gas Emissions: The Combined Potential of Hybrid Technology and Behavioral Adaptation. SAE 2013-01-1282. SAE World Congress, Detroit, MI, April 16–18. (http://papers.sae.org/2013-01-1282/).
Santini, D.J., Y. Zhou, and A. Vyas (2012). An Analysis of Car and SUV Daytime Parking for Potential Opportunity Charging of Plug-in Electric Powertrains. EVS26, Los Angeles, CA, May 6–9. (http://toc.proceedings.com/16245webtoc.pdf)
Santini, D.J. and Y. Zhou (2015). Potential to Electrify Miles with Different Plug-in Vehicle Innovation Paths. TRB 15-3263, presented at the Annual Meeting of the Transportation Research Board, Washington, DC (Jan.). (http://amonline.trb.org/).

Seisler (2014). Webinar on the Role of Government in Natural Gas Vehicle Policymaking and Strategy Process. Alternative Fuels Data Center, National Renewable Energy Laboratory (http://www.afdc.energy.gov/cleancities/webinars/#/webinar_6). (Dec. 15).
Shepard, S. (2014). Electric Vehicle Market Forecasts Global Forecasts for Light Duty Hybrid, Plug-In Hybrid, and Battery Electric Vehicle Sales and Vehicles in Use: 2014-2023, Navigant Research. (https://www.navigantresearch.com/research/electric-vehicle-market-forecasts).

Smart, J. (2014) Workplace Lessons Learned through the Nation's Largest PEV Charging Projects. DOE Workplace Charging Challenge Summit Alexandria, VA. (Nov. 18). (http://avt.inl.gov/pdf/EVProj/WorkplaceChargingDataInsights.pdf)

Smart, J. and J. Francfort (2015). Charging Infrastructure Use Profiles and Installation Costs for 17,000 Units Annual Meeting of the Transportation Research Board: Session on Plug-in Electric Vehicle Infrastructure and Driver Behavior: Issues and Solutions for Continued Market Growth. Washington, DC. (Jan 12). (http://pressamp.trb.org/aminteractiveprogram/EventDetails.aspx?ID=32487).

Smart, J. and S. White (2014). Electric Vehicle Charging Infrastructure Usage Observed in Large-scale Charging Infrastructure Demonstrations. Presented to the National Academy of Sciences Committee on Overcoming Barriers to EV Deployment open-session meeting, Irvine, CA (Feb. 25). (http://avt.inel.gov/pdf/EVProj/EVInfrastructureUsage.pdf).

Solomon, M. (2014). The Multi-State ZEV Action Plan. NESCAUM. (Oct. 16). (http://www.dem.ri.gov/zevplanmou.pdf).

Southern California Edison (2013). Charged Up: Southern California Edison's Key Learnings About Electric Vehicles, Customers, and Grid Reliability (Aug. 6) (http://newsroom.edison.com/internal_redirect/cms.ipressroom.com.s3.amazonaws.com/166/files/20136/SCE-EVWhitePaper2013.pdf).

Tal, G. and M.A. Nicholas (2013). Studying the PEV Market in California: Comparing the PEV, PHEV, and Hybrid Markets. Electric Vehicle Symposium 27, Barcelona, Spain (Nov. 17-20). (http://www.arb.ca.gov/html/ca_pevmarket_study_ucdits.pdf)

Tal, G. et al (2014). Charging Behavior Impacts on Electric VMT: Evidence from a 2013 California Drivers Survey. Paper TRB 14-3556. Annual Meeting of the Transportation Research Board, Washington, DC (Jan.) (http://docs.trb.org/prp/14-3556.pdf).

U.S. Department of Energy (2014). Workplace Charging Challenge: Progress Update 2014: Employers Take Charge. U.S. Department of Energy: Energy Efficiency and Renewable Energy Report DOE/GO-102014-4561 (November). (http://www.afdc.energy.gov/uploads/publication/wpc_2014_progress_report.pdf)

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2015). www.fuel economy.gov the official U.S. government source for fuel economy information. http://www.fueleconomy.gov/feg/phevnews.shtml

Vyas, A. (2015). personal communication on unpublished analysis of the 2001 National Household Travel Survey.

Voelker, J. (2012). Landlords Vs Tenants With Electric Cars: The Latest Round. Green Car Reports. (May 15). (http://www.greencarreports.com/news/1076150_landlords-vs-tenants-with-electric-cars-the-latest-round.).

Yuksel, T., and J. Michalek. (2015). Effects of Regional Temperature on Electric Vehicle Efficiency, Range, and Emissions in the United States. Working paper. Preliminary results presented at the Annual Meeting of the Transportation Research Board, Washington, DC. Jan. Carnegie Mellon University. (http://pubs.acs.org/doi/abs/10.1021/es505621s).