Californias
Advanced Clean Cars
Midterm Review

Appendix G:
Plug-in Electric Vehicle In-Use and Charging Data Analysis

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California Environmental Protection Agency
Air Resources Board

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I. Introduction

In 2012, the California Air Resources Board (ARB or the Board) adopted the Advanced Clean Cars (ACC) program, including increased requirements for the zero-emission vehicle (ZEV) regulation). When the increased requirements for the ZEV regulation were adopted, only two manufacturers had certified plug-in hybrid electric vehicles (PHEV),[1] and little was known about how those vehicles would be driven, what the emissions benefits could be, how often those vehicles would be plugged in, or how the second or third owners of the vehicles would drive or charge the vehicles. Knowing there was much to learn about PHEVs and range extended battery electric vehicles (BEVx), the Board directed staff in Resolution 12-11 to study "in-use data for range extended battery electric vehicles and plug-in hybrid electric vehicles, and, if warranted, propose appropriate modifications to treatment and credits for these vehicle types".

Soon after the Board adopted the ACC regulations, manufacturers (notably, Honda, Toyota, Ford, and General Motors) requested (both in front of the Board and during meetings with staff) that staff be directed to study the electric vehicle miles traveled (eVMT) from PHEVs as compared to BEVs. Manufacturers (General Motors, Ford, Toyota, and Honda) submitted trip level data to Idaho National Laboratory (INL) for analysis, which was later presented to the Board at its October 2014 hearing.[2] Since 2014, manufacturers have submitted the same trip level data (as well as additional data and data from other manufacturers) for ARB to analyze.

This Appendix G describes the in-use trip level vehicle data collected from various PHEVs, BEVs, and BEVxs. To provide a complete picture of how "ZEV-like" a PHEV is, staff analyzed two metrics, electric only trips (e-trips) and zero emission vehicle miles travelled (zVMT). As seen from the data, driving data from the same vehicle model can vary widely dependent on when and under what driving conditions the data was collected. Vehicles with similar electric ranges have varied eVMT and zVMT. The data also shows that EV project participants were a limited set of very early adopters and vehicles purchased by a broader group were less interested in maximizing %eVMT and %zVMT. Although newer PHEVs have higher VMT, their average annual eVMT and zVMT remains constant. When possible, staff looked at data based on California being the "home state", and leased vehicles vs. purchased vehicles, and seasonal differences. Staff also analyzed the activity data received from manufacturers to better understand the likely impacts on criteria pollutants such as hydrocarbons (HC) and oxides of nitrogen (NOx) from the various PHEVs.

This analysis will lead into Appendix I, which describes various ways to use data in this analysis in alternative credit schemes for PHEVs, BEVxs, and BEVs.

II. Data Overview

Seven manufacturers submitted data for eleven different plug-in vehicle (PEV) models, which includes PHEVs, BEVxs, and BEVs. The data reported varied widely across manufacturers, and therefore analysis was limited for some models. This section will describe the type of data

[1] Toyota Plug-in Prius and Chevrolet Volt
[2] A description of INL's analysis is found on page 52. A description of the Department of Energy's EV Project is found on page 51.

provided to staff, organized by manufacturer, as well as the number of vehicles included in each data set.

II.A. Description of Data from Manufacturers

II.A.1. BMW

II.A.1.i. Type and Number of Vehicles in Sample

Vehicle data was provided for both the i3 BEV and the i3 with range extender (REX) which is the only vehicle to date that is designated as a BEVx in the ZEV regulation. The number of BEV and BEVx vehicles sold in each year (not necessarily the model year), are listed in Table 1.

Table 1 - Number of Vehicles in the BMW Dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/ Retail Year/ 1st Record Date	Number of Vehicles
BMW i3 BEV	BEV	Retail Year = 2014	2,525
		Retail Year = 2015	1,654
		Retail Year = 2016	14
BMW i3 REX	BEVx	Retail Year = 2014	2,976
		Retail Year = 2015	5,296
		Retail Year = 2016	37

II.A.1.ii. Location of Vehicles in Sample

BMW provided a national dataset. There was no global positioning system (GPS) flag in the data to break out the California or Section 177 ZEV state[3] vehicles.

II.A.1.iii. Driving Data Provided

BMW provided ARB with summary data tables that included, for each vehicle, the total vehicle miles travelled (VMT) along with the corresponding total number of days since the vehicle was placed into service (sold or leased). A retail sales date was provided for each vehicle. Unlike the data provided by most other manufacturers, the BMW data did not include details about individual vehicle trips and thus, provided for more limited analysis in understanding how the vehicles were being used.

II.A.1.iv. Charging Data Provided

No charging data was provided by BMW in the data sample.

II.A.1.v. Data Exclusions and Filtering

For the BMW data sets, there was no additional processing of the data required prior to analysis as only summary data (total miles and days) and no individual trip data was provided. However, BMW indicated that the raw data attached have been filtered for read out errors such as counter resets, data transmission errors caused by mobile network connection loss and battery

[3] Through the provisions of the Clean Air Act identified as Section 177, nine states have adopted California's ZEV regulation: Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont. These nine states are commonly referred to as the Section 177 ZEV states.

disconnects during dealer visits. Data collection was carried out through BMW internal Tele Service Report (TSR) with customer consent.

II.A.2. FORD

II.A.2.i. Type and Number of Vehicles in Sample

Vehicle data was provided for the Focus BEV, the Fusion Energi PHEV and the C-Max Energi PHEV. Details on the number of vehicles and model years within each vehicle are provided in Table 2 below.

Table 2 - Number of Vehicles in the Ford Dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/ Retail Year/ 1st Record Date	Number of Vehicles
Ford Focus Electric	BEV	Retail Year = 2012	457
		Retail Year = 2013	1,239
		Retail Year = 2014	1,648
		Retail Year = 2015	858
		Retail Year = 2016	7
		unknown	9
Ford C-Max Energi	PHEV	Retail Year = 2013	5,017
		Retail Year = 2014	2,897
		Retail Year = 2015	2,020
		Retail Year = 2016	6
		Unknown	313
Ford Fusion Energi	PHEV	Retail Year = 2013	3,258
		Retail Year = 2014	4,927
		Retail Year = 2015	3,389
		Retail Year = 2016	768
		Unknown	500

II.A.2.ii. Location of Vehicles in Sample

The data provided by Ford included truncated global positioning system (GPS) data for each trip which allowed for a determination of the vehicle's approximate location (only to within a hundred mile quadrant). As seen in Table 3, this data was used by ARB to determine if a vehicle was primarily being operated within California. Based on an analysis of the data, approximately 41% of the vehicles had the majority of their trips within California. The Ford Focus Electric had the largest proportion of trips in California and the C-Max Energi had the lowest.

Table 3 - Number of Ford Vehicles for California Trips

Vehicle	VINs with Trip Data	VINs with >50% of trips in CA	% of VINs with >50% CA trips
FORD C-Max Energi	10,253	3,617	35.3%
FORD Focus Electric	4,218	2,128	50.5%
FORD Fusion Energi	12,842	5,439	42.4%
TOTAL	27,313	11,184	40.9%

Ford provided additional data fields that indicated the "Home State" for each vehicle based on its own algorithm to determine the location of the vehicle. Ford's data field provided similar results compared to the staff's analysis; with only a slightly larger number of vehicles designated as California vehicles as seen in Table 4.

Table 4 - Number of Ford Vehicles for California Designated "Home State" Vehicles

Vehicle	Vehicle Counts	Vehicle Counts with CA as Home State	% of Vehicles with CA as Home State
FORD C-Max Energi	10,253	4,394	42.9%
FORD Focus Electric	4,218	2,421	57.4%
FORD Fusion Energi	12,842	5,545	43.2%
TOTAL	27,313	12,360	45.3%

II.A.2.iii. Driving Data Provided

Ford provided ARB with a large data set that included 125 data fields for each record, however, many of the fields were not relevant to the analysis. The relevant data fields related to driving included: trip information that allowed ARB to determine fuel and electricity used for the trip; the time, date, and distance of the trip; and information about the battery state of charge.

II.A.2.iv. Charging Data Provided

The data provided included charging information indicating time and date of charging, type of charging (e.g., level 1, level 2), and information about the amount of charging that occurred during each event.

II.A.2.v. Data Exclusions and Filtering

For the Ford data set, the trip and charge data was extracted from the manufacturer's data set to prepare for data consolidation in ARB's analysis.

II.A.3. GENERAL MOTORS

II.A.3.i. Type and Number of Vehicles in Sample

General Motors provided ARB with data from the Chevrolet Volt PHEVs that were included in the EV Project. The EV project is described later in Section 7 of this Appendix. This data set is limited in that it reflects a small number of vehicles relative to what GM has subsequently sold as well as that it represents a subset of early vehicle owners that were provided charging equipment and voluntarily participating in a program to study their charging habits. Details regarding the number of vehicles and model years are provided in Table 5 below.

Table 5 - Number of Vehicles in the General Motors Dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/ Retail Year/ 1st Record Date	Number of Vehicles
Chevrolet Volt	PHEV	MY= 2011	207
		MY= 2012	1,129
		MY= 2013	817
		Unknown	1

II.A.3.ii. Location of Vehicles in Sample

General Motors provided a national data set and a field denoting a State for each Chevrolet Volt based on its own algorithm. No additional location information was provided as a means to verify or independently determine whether the vehicle was primarily used in California. Based on the data set received, as shown in Table 6, approximately 31% of the vehicles were California based vehicles.

Table 6 - Number of General Motors Vehicles for California Designated "Home State" Vehicles

Model Year	Total Vehicle Counts	CA Vehicle Counts	% CA Vehicles
2011	207	53	25.6%
2012	1,129	294	26.0%
2013	817	330	40.4%
Unknown	1	0	0.0%
TOTAL	2,154	677	31.4%

II.A.3.iii. Driving Data Provided

General Motors provided ARB with pre-processed data tables along with raw data tables for the sample vehicles. The driving data allowed staff to determine: the fuel and electricity used for the trip; the time, date, and distance of the trip; and information about the battery state of charge.

II.A.3.iv. Charging Data Provided

General Motors did not provide any location (home/work/other) or type (levels) data on charges. However, staff came up with a logic for determining what counted as a charge and were able to calculate total charge count.

II.A.3.v. Data Exclusions and Filtering

GM data utilized for this analysis is the same dataset included in the EV Project. As shown in Table 6, this dataset only spans over 2011 – 2013 model years. More information on EV project is provided in Section 7 of this Appendix.

II.A.4. HONDA

II.A.4.i. Type and Number of Vehicles in Sample

Vehicle data was provided for both the Honda Fit BEV and the Honda Accord PHEV. Table 7 provides details on the number of each vehicle and model year that were provided.

Table 7 - Number of Vehicles in the Honda Dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/ Retail Year/ 1st Record Date	Number of Vehicles
Honda Fit	BEV	First Record Date in CY2012	80
		First Record Date in CY2013	559
		First Record Date in CY2014	6
Honda Accord	PHEV	First Record Date in CY2012	189

II.A.4.ii. Location of Vehicles in Sample

The Honda dataset was a national dataset with no GPS information provided. However, most of those vehicles were sold in CA.

II.A.4.iii. Driving Data Provided

Honda provided ARB with a trip data table for each selected vehicle. Each vehicle's trip data table provides the records for each key-off event. The driving data allowed staff to determine: the fuel and electricity used for the trip; the time, date, and distance of the trip; and information about the battery state of charge.

II.A.4.iv. Charging Data Provided

Honda provided ARB with a charge data table for each selected vehicle. Each vehicle's charge data table provides the records for each charge-off event. The charging data allowed ARB to determine the time, the presumed location (home/not home), the type of charging (e.g., level 1, level 2) for Fit EV charge events, and the battery state of charge information for both the Accord PHEV and the Fit EV.

II.A.4.v. Data Exclusions and Filtering

Data was excluded for vehicles that had accumulated less than 90 days-worth of trips and for all research and testing vehicles. All data records prior to a vehicle's retail start date were excluded. For the Honda Accord PHEV, additional records were excluded for vehicles with less than 1000 miles and for all vehicles when a customer does not have a paired phone to transmit data. For the Honda data set, the trip and charge data was extracted from the manufacturer's data set to prepare for data consolidation in ARB's analysis.

II.A.5. NISSAN

II.A.5.i. Type and Number of Vehicles in Sample

Vehicle data was provided for the Nissan Leaf BEV. Table 8 below provides details on the number of each vehicle and model year that were provided.

Table 8 - Number of Vehicles in the Nissan Dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/ Retail Year/ 1st Record Date	Number of Vehicles
Nissan Leaf	BEV	MY = 2011	4,052
		MY = 2012	2,867
		MY = 2013	4,043
		MY = 2014	1,155
		MY = 2015	98

II.A.5.ii. Location of Vehicles in Sample

Data was provided for vehicles determined by Nissan to be California-based vehicles. Nissan only sent data for vehicles with great than 50% of trips in CA so all records sent are considered California based vehicles. For those vehicles, data was provided for vehicle trips within and outside of California, which can be approximated by using the truncated GPS data fields. Data provided to ARB included a subset of the vehicles from the EV Project (i.e., only the California-based vehicles) as well as additional California-based vehicles that were not a part of the EV Project.

II.A.5.iii. Driving Data Provided

Nissan provided ARB with a trip data table and a vehicle table. A data dictionary was also provided. The vehicle table allowed ARB to determine the model year, on-board charger rating, and purchase agreement data that indicated whether the vehicle was purchased or leased and, if leased, the annual mileage limitations of the lease agreement (i.e., 12,000 or 15,000 annual miles pre-paid). The data also indicated whether the vehicle was privately owned or purchased for a fleet. The driving data allowed ARB to determine the time, date, and distance of the trip, and information about the battery state of charge.

II.A.5.iv. Charging Data Provided

Nissan provided ARB with a charge data table. The charging data allowed ARB to determine the time and date of charging events, the type of charging (e.g., level 1, level 2, direct current or DC fast charge), information about the battery state of charge (SOC), and information about the charging location (inferred location of home/work/other per Nissan proprietary algorithm).

II.A.5.v. Data Exclusions and Filtering

Data for 2011 through 2012 model year vehicles was subject to a trip-by-trip approval by the driver to transmit the data to Nissan. As a result, a significant portion of the trip data is missing for these model years. Data for 2013 through 2015 model year vehicles was subject to a monthly approval by the driver and resulted in more complete data records. Data was excluded for vehicles that had accumulated less than 90 days worth of trips and for records with odometer values less than 124 miles (200 kilometers) to avoid transport and dealer use. Some additional records were excluded due to invalid data in critical fields. For the Nissan data set, the trip and charge data were extracted from the manufacturer's data set to prepare for data consolidation in ARB's analysis.

II.A.6. TESLA

II.A.6.i. Type and Number of Vehicles in Sample

Tesla provided ARB with data for Model S BEVs. Table 9 below tabulates the number of vehicles in the sample set that were placed in service each year (not necessarily model year).

Table 9 - Number of Vehicles in the Tesla Dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/ Retail Year/ 1st Record Date	Number of Vehicles
Tesla Model S	BEV	First Record Date in CY2012	229
		First Record Date in CY2013	18,749
		First Record Date in CY2014	10,967
		First Record Date in CY2015	7,690

II.A.6.ii. Location of Vehicles in Sample

The data included vehicles placed in the United States.

II.A.6.iii. Driving Data Provided

Tesla provided ARB with a pre-filtered summary table that included the beginning and ending odometer and dates, the recorded miles and days, and the annual run-rate (the annualized vehicle miles travelled based on 365 days per year).

II.A.6.iv. Charging Data Provided

No charging data was provided in the Tesla data sample.

II.A.6.v. Data Exclusions and Filtering

Tesla provided ARB with a pre-filtered summary table that only included vehicles that had at least 30 days of recorded data and a minimum of 3,000 recorded odometer miles. For the Tesla data set, there was no additional processing of the data required prior to analysis as only summary data (total miles and days) and no individual trip data was provided.

II.A.7. TOYOTA

II.A.7.i. Type and Number of Vehicles in Sample

Toyota provided ARB with data for Prius PHEVs. Table 10 below provides details of the number of vehicles by year the vehicle was placed in service (not necessarily model year) that were included in the sample.

Table 10 - Number of Vehicles in the Toyota Dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/ Retail Year/ 1st Record Date	Number of Vehicles
Toyota Prius	PHEV	First Record Date in CY2013	1,423
		First Record Date in CY2014	100

II.A.7.ii. Location of Vehicles in Sample
Toyota provided a national dataset with no GPS information.

II.A.7.iii. Driving Data Provided
Toyota provided ARB with trip data tables for each selected vehicle. The driving data allowed ARB to determine: the fuel and electricity used for the trip; the time, date, and distance of the trip; and information about the battery SOC.

II.A.7.iv. Charging Data Provided
Toyota provided ARB with charge data tables for each selected vehicle. The charging data allowed ARB to determine the time and date of charging events and information about the battery SOC.

II.A.7.v. Data Exclusions and Filtering
For the Toyota data set, the trip and charge data was extracted from the manufacturer's data set to prepare for data consolidation in ARB's analysis.

II.B. Summary Tables of Manufacturer-Provided Data
Table 11 summarizes the vehicle counts per manufacturer for the data that was provided to ARB. Cumulatively, data was provided from seven manufacturers for more than 90,000 vehicles.

Table 11 - Summary of Vehicles in the ARB dataset

Vehicle	Type of Plug-in Electric Vehicle	Model Year/Retail Year/1st Record Date	Number of Vehicles
BMW i3 BEV	BEV	Retail Year = 2014-2016	4,193
BMW i3 REX	BEVx	Retail Year = 2014-2016	8,309
Ford C-Max Energi	PHEV	MY=2013-2016*	10,253
Ford Focus Electric	BEV	MY=2012-2016*	4,218
Ford Fusion Energi	PHEV	MY=2013-2016*	12,842
GM Chevrolet Volt	PHEV	MY=2011-2013*	2,154
Honda Fit	BEV	First Record Date in CY2012-2014	645
Honda Accord	PHEV	First Record Date in CY2013	189
Nissan Leaf	BEV	MY=2011-2015	12,215
Tesla Model S	BEV	First Record Date in CY2012-2015	37,635
Toyota Prius	PHEV	First Record Date in CY2013-2014	1,523

***Unknown – Some vehicles were not identified as a specific model year**

Tesla provided summary data on the largest number of vehicles. Ford provided detailed trip and charge data for the largest number of vehicles.

Table 12 provides the record counts for the trip and charge data provided by the manufacturers by vehicle type. Minor differences in vehicle counts may occur in different data sets.

Table 12 - Summary of Number of Vehicles

Vehicle	Type of Plug-in Electric Vehicle	Trip Data	Charge Data
BMW i3 BEV	BEV	Total miles & days for 4,193 vehicles (no individual trip data)	None
BMW i3 REX	BEVx	Total miles & days for 8,309 vehicles (no individual trip data)	None
Ford C-Max Energi	PHEV	13,813,288 individual records for 10,253 vehicles	12,880,589 individual records for 10,162 vehicles
Ford Focus Electric	BEV	4,940,786 individual records for 4,218 vehicles	5,074,632 individual records for 4,222 vehicles
Ford Fusion Energi	PHEV	15,557,891 individual records for 12,842 vehicles	14,535,732 individual records for 12,897 vehicles
GM Chevrolet Volt	PHEV	3,058,146 individual records for 2,154 vehicles	1,623,088 individual records for 2,154 vehicles
Honda Fit	BEV	817,874 individual records for 645 vehicles	175,108 individual records for 645 vehicles
Honda Accord	PHEV	180,575 individual records for 189 vehicles	41,972 individual records for 189 vehicles
Nissan Leaf	BEV	26,129,430 individual records for 12,215 vehicles	6,556,654 individual records for 12,215 vehicles
Tesla Model S	BEV	Total miles & days for 37,635 vehicles (no individual trip data)	None
Toyota Prius	PHEV	2,206,174 individual records for 1,523 vehicles	449,434 individual records for 1,523 vehicles

III. Analysis Methods for OEM Data Provided

III.A. Calculation methods

To assess the relative performance of the BEVs and PHEVs, several different ways of categorizing the total vehicle usage were studied. In almost all cases, comparisons were made relative to the total annual miles of the vehicle or VMT. In this analysis, total VMT was calculated as the annual miles traveled, regardless of the energy source (e.g., electricity, gasoline).

A recent method to quantify the behavior of PHEVs is to look at the portion of total VMT that is a result of electric operation or electric vehicle miles traveled (eVMT). For this analysis, the calculated eVMT represents an estimate of the grid energy apportioned miles traveled. eVMT is generally considered a good representation of a vehicle's greenhouse gas (GHG) benefits, since most GHG emission occur during a vehicle's operation (as opposed to its engine start emissions). For blended PHEVs like the Ford, Honda, and Toyota models in this analysis, apportioning miles traveled to the grid or to gasoline power is not a simple task as there are periods of operation where both energy sources are being used to propel the vehicle. Details are provided below for some of the techniques used to apportion such blended miles to the most appropriate category.

While eVMT does appear to reasonably represent the GHG performance of a PHEV, the non-linearity of criteria pollutant emissions (e.g., hydrocarbons, oxides of nitrogen) led staff to explore additional ways to categorize the usage that might relate better to the criteria pollutant performance. Two such metrics included electric only trips (e-trips) and zero-emissions vehicle miles traveled (zVMT). The computed e-trips represent the number of trips without any internal combustion engine (ICE) operation. Given the dominant impact of initial engine start-up on criteria pollutant emissions, this metric might provide an indication of start-up emissions that are avoided. However, as it only counts the number of trips without engine operation, short trips and long trips are equally weighted. Thus, staff also considered the sum of all e-trip miles, or zVMT. This represents the portion of total VMT that is met with trips that mimic a BEV with no directly-emitted criteria pollutant emissions and can provide a relative perspective of the criteria pollutant benefit.[4]

As noted above, the calculation of eVMT is fairly complicated for blended hybrids and varied somewhat based on the available data in the sample. In general terms, the analysis used a method to assess typical gasoline only consumption rates and grid energy only consumption rates and then use those typical values to apportion miles traveled while both energy sources were being used. However, the details varied as to how that was accomplished in each of the manufacturer's data sets.

The Toyota and General Motors data sets provided the computed data; therefore staff did not have to process the data further before analysis for eVMT. For the Ford data set, the eVMT data used in this analysis was calculated by multiplying the VMT by the electric usage ratio. This ratio is computed by dividing the electric energy consumed by the total energy (gas plus electric) consumed. This calculation required assumptions to be made for vehicle fuel economy. A conversion rate of 0.07112 gallons per kilowatt-hour (kWh) was used based on the assumed rates of 38 miles per gallon and 370 watt-hours per mile. These rates were based on the United States Environmental Protection Agency (U.S. EPA) labels for miles per gallon

[4] See Appendix H for test results from ARB's in-house PHEV testing.

(mpg)[5] for the 2015 model year Ford C-Max Energi and Fusion Energi PHEVs. The formula used for eVMT for Ford is as follows:

$$eVMT_{Ford} = \frac{(0.7112 \times electric\_consumption)}{((0.7112 \times electric\_consumption + gas\_consumption)}$$

For the Honda Accord PHEV, eVMT was calculated using the logic provided by Honda in their documentation describing the data fields. The average fuel economy (mpg) was calculated for each vehicle as the sum of the cumulative gasoline engine powered charge sustaining (CS) miles divided by the cumulative CS fuel consumed. For each trip, the grid energy powered charge depleting (CD) miles were computed as the total distance minus the CS miles. The eVMT was computed by taking the CD mode miles and subtracting the product of the average mpg by the CD mode fuel consumption.

Trips were analyzed for all individual trip records where the vehicle moved. The formulas vary by manufacturer depending on the data fields that were provided and specific context, but in general, the calculations for eTrips and zVMT are as follows:

eTrips = True if

electricity (battery energy) consumption >0 and
gasoline consumption = 0 and
distance >0
and vehicle average speed > 0

zVMT = cumulative miles traveled for records where eTrips are True

The percentage of eVMT and zVMT were multiplied by the odometer change based VMT to scale up the eVMT and zVMT miles where the odometer changes exceeded the recorded VMT in the manufacturer data sets which included odometer data. Scaling up the eVMT and zVMT based on the odometer changes assumes that the non-reported miles would reflect the same usage patterns as those reported. This was only done for the Honda dataset. Ford, Toyota and Honda provided odometer data that could be scaled up to match the odometer differences.

III.B. Data output format

The trip data was consolidated into a table that reflected a record for each vehicle identification (ID) with the type of vehicle and model year, the start and end date and time, the start and end SOC percentage, the vehicle miles and the eVMT (in miles), the gas and/or electricity consumed, the average speed, and the starting odometer reading. For each trip record, the time period in days and the change in the SOC were computed. The charge data was consolidated into a table that reflected a record for each vehicle ID with the type of vehicle and model year, the start and end date and time, the type of charge, the start and end state of charge percentage, and the charge location. For each charge record, the time period in days

[5] EPA 2016. United States Environmental Protection Agency fuel economy website. http://www.fueleconomy.gov. Accessed September 28, 2016

and the change in the SOC were computed. The trip and charge data were summarized into monthly and annualized data sets by summing per individual vehicle the number of trips or charges, changes in date/time in days, mileage changes by type (VMT, eVMT, zvMT), changes in states of charge by appropriate groupings (such as by type of charge and location of charge). The odometer changes over time per vehicle were also computed.

The annualized and monthly data set were filtered to only utilize results for records that had VMT within 85% of the odometer change over the time period. Filtering also excluded records for vehicles that did not have at least 24 days in the monthly data set or at least 30 days for the annualized data set, and excluded records if the odometer change exceeded one million miles. These filtering selections were used to better represent the activity of these vehicles by filtering out data with extreme values that might skew the data results.

III.C. Discussion of uncertainties in results due to data issues

The voluntary data sets provided by the OEMs were pre-processed and pre-filtered in a variety of ways prior to receipt at ARB, further described in Section II.A; there was no standardized reporting method process. The data received represents a limited number of vehicles over varying time periods. The algorithms for capturing data vary across the OEMs and interpretation of the data sets relied on and is limited by the information provided by each OEM.

There are some issues with the resolution of the data captured, specific to each OEM's data set, for which different post-processing and filtering methods might produce different results. For instance, some records may show no gas fuel consumption with electric energy consumption above zero, but for which no eVMT was recorded though the VMT is noted as above zero. This would indicate that there is a low end threshold for the electric mileage captured (no or truncated decimals). Thus, a sum of the eVMT would exclude miles when the electric energy consumed was very small. If instead of the eVMT, the VMT is summed whenever electric energy consumed is above zero while the gas energy consumption was zero, this sum could be higher than the sum of the designated electric miles.

Inferred charge location data is based upon proprietary algorithms using trip and charge data and vary by OEM. These algorithms may not provide 100% accurate results.

Missing data can result in understated results, such as for trips or mileage per day computations that use the sum of the trips or miles data divided by the number of days across a time period. Computing such rates relies on an assumption that all trip and mileage data in that time period have been accounted for which is not always the case. When available, the actual odometer change over time has been used to avoid using the understated mileage sums resulting from missing records.

In virtually all of the data samples, some trip data may not have been captured for a variety of reasons such as lack of cellular service coverage or manufacturer specific parameters that excluded certain types of trips. The missing trips become noticeable when differences in a vehicle's odometer readings significantly exceed the sum of the individual trip distances logged. As discussed above in the processing steps, staff excluded data with odometer differences (i.e., difference between year-start and year-end odometers) that exceeded 85% of reported annual VMT prior to computing average rates (e.g., if more than 15% of the data was missing, the data was excluded). Additionally, for vehicles with some missing data (but less than 15%), if odometer data was available, the sum of individual trip distances were scaled up to match the odometer reading differences. This scaling factor was also applied on eVMT and zVMT.

IV. Trip Results

IV.A. Annual means for each vehicle model

To compute the VMT values, the data was filtered based on the type of data that was received from each manufacturer, as is notated in Table 13 for BEVs and Table 14 for PHEVs. Filtering the data sets using alternative methods could provide different results. The mean is a good measure for a normal distribution in which case it will have a similar value to the median. The median is usually better for a skewed distribution. Tesla reflects this more than the others as there are some high mileage outliers that do not represent the majority of the vehicles.

Table 13 - Annual VMT for BEVs

Type of Vehicle	VMT – Mean	VMT - Median
BMW i3 BEV[1]	7,916	7,544
Ford Focus Electric[2]	9,741	9,392
Honda Fit[3]	9,789	9,466
Nissan Leaf[2]	10,294	9,989
Tesla Model S[1]	13,494	12,334
[1]No filtering (OEM provided summary data per vehicle, not individual trip data)		
[2]Filtered to only include vehicles with >30 days, based on odometer differences (not VMT per trip sum)		
[3]Filtered to only include vehicles with >30 days, based on VMT per trip sums (no odometer data was provided)		

For some of the PHEVs, as noted in Table 14, the eVMT and zVMT were scaled up by multiplying by the odometer changes divided by the VMT trip sums, prior to computing the means and medians in order to provide more comparable results. For example, if the individual trip data captured 8,000 miles of operation, of which 4,000 were electric miles (or 50% eVMT) but the odometer reflected 10,000 actual miles of operation, the results were scaled to show that 5,000 (or 50%) of the 10,000 actual miles were electric miles.

Except for Tesla, the BEVs generally have lower annual total VMT than PHEVs. However, PHEVs VMT can be analyzed in various ways including eVMT and zVMT which is also listed in Table 14. The next section will focus on VMT, eVMT, zVMT and e-trips.

Table 14 - Annual VMT for PHEV Vehicles

Type of Vehicle	VMT - Mean	VMT - Median	eVMT - Mean	eVMT – Median	zVMT - Mean	zVMT - Median
BMW i3 REX BEVx[1]	9,063	8,387	8,356	7,841	unknown	unknown
Ford C-Max Energi[2]	13,920	12,841	4,574	4,546	2,525	2,305
Ford Fusion Energi[2]	15,076	13,897	4,776	4,692	2,368	2,014
GM Chevrolet Volt[2]	12,403	11,698	8,924	8,815	7,313	7,135
Honda Accord[3]	15,221	14,766	3,246	3,108	1,471	1,337
Toyota Prius[4]	15,283	14,159	2,304	2,175	589	318
[1]No filtering or scaling (OEM provided summary data per vehicle, not individual trip data)						
[2]Filtered to only include vehicles with >30 days & VMT sum within 85% of odometer change; Trip sums scaled up by Odometer changes/VMT sum						
[3]Filtered to only include vehicles with >30 days, based on VMT per trip sums (no odometer data was provided)						
[4]Filtered to only include vehicles with >30 days & VMT sum within 85% of odometer change; Odometer changes were slightly less than VMT sums so no scaling was appropriate						

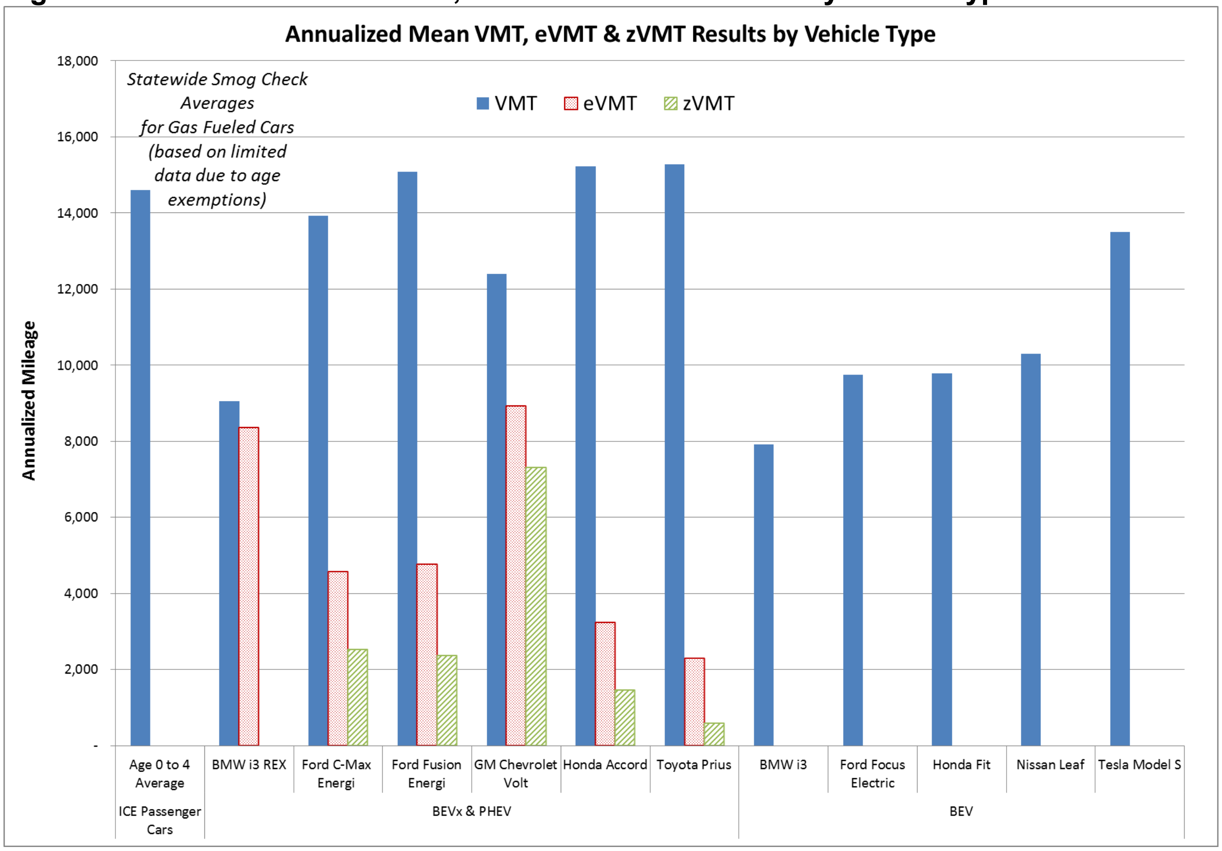
IV.B. Annual Percent VMT, eVMT, zVMT, and e-trips

This section summarizes the annual percent VMT, eVMT, zVMT and e-trips across model types and with conventional ICE vehicles VMT. BEV and PHEV data was calculated as described in III above. Updated annualized mileage for ICE vehicles used in the following chart was computed using odometer readings for passenger cars from calendar year 2001 through 2014 statewide California Smog Check program data. Relative to older data, the new statewide average VMT for ICE passenger car vehicles did not reflect any significant difference (e.g., due to recessionary years). Paired odometer readings per individual vehicle identification number (VIN) from consecutive biennial inspections were used to compute the mileage changes which were annualized to 365 days per year for annual mileage rates. For relatively new vehicles, similar to the majority of the PHEVs and BEVs in this data set, smog check data has more limited record counts as most vehicles are not required to have smog checks until they are older; however, there are inspections required for a subset of vehicles including those that have been re-sold or that have been transferred from out of state into California and those inspections were the primary source used to determine annualized mileage in the first few years of a vehicle's life.

Figure 1 below provides the average annual VMT, eVMT, and zVMT by vehicle model for all vehicles in the sample. Note that for BEVs, eVMT and zVMT are equal to their overall VMT and so only VMT is shown for simplification. Based on the data provided by the OEMs, it appears that Ford, Honda, and Toyota PHEVs have similar overall annual mileage to conventional gasoline-powered vehicles. The GM Volt PHEV and the Tesla Model S have slightly lower annual mileage rates. The rest of the PHEVs and BEVs have much lower annual mileage rates. Between similar range BEVs, annual VMT varies, most notably the BMW i3 has a much lower annual average.

In comparing the PHEV eVMT to BEV eVMT, blended-type PHEVs (Ford PHEVs, Honda Accord, and Toyota Prius) have less than 40% eVMT. zVMT is even lower, ranging from 10-25% for blended PHEVs. GM Volts, however, have significantly higher eVMT (75%) and zVMT (~60%) than the other PHEVs analyzed in this dataset.

Figure 1 - Annualized Mean VMT, eVMT and zVMT results by vehicle type



For the Ford and GM PHEV datasets, ARB received some information to differentiate California vehicles. To take a closer look at annual mileage by vehicle type per model year, Figure 2 compares the annual mileage nationally (including California vehicles) for these vehicles and compares them to California vehicles

Figure 2 - Annual Mileage by Vehicle Type per Model Year for PHEVs for US and CA vehicles

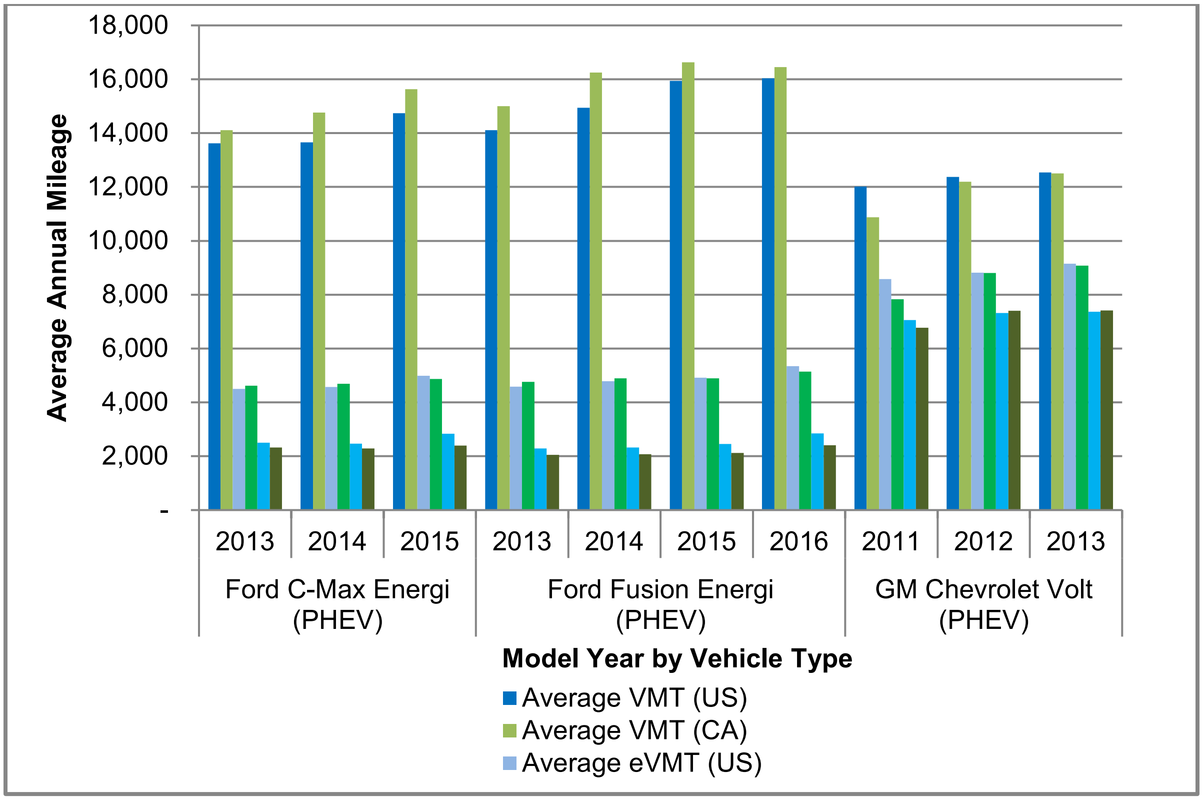


Figure 2 above shows the average annual mileage by PHEV per model year across the U.S. including California vehicles. For example, the 2013 model year Ford C-Max Energi data given to ARB included trips in 2013, 2014, 2015, and 2016 calendar years. The average annual mileage reported in Figure 2 above represents an average of all four years for the 2013 model year vehicles. Although newer PHEVs have higher VMT, their average annual eVMT and zVMT remained constant. This may mean that as these vehicles were purchased by a broader group of consumers than the earliest adopters, there was less consumer interest in maximizing %eVMT and %zVMT or that the newer purchasers had less access or desire to use charging. It is also possible that some or all of the %eVMT and %ZMT reductions may be due to gas prices reductions that occurred during this period; an owner may not be motivated to charge the battery as frequently if they consider gas to be inexpensive.

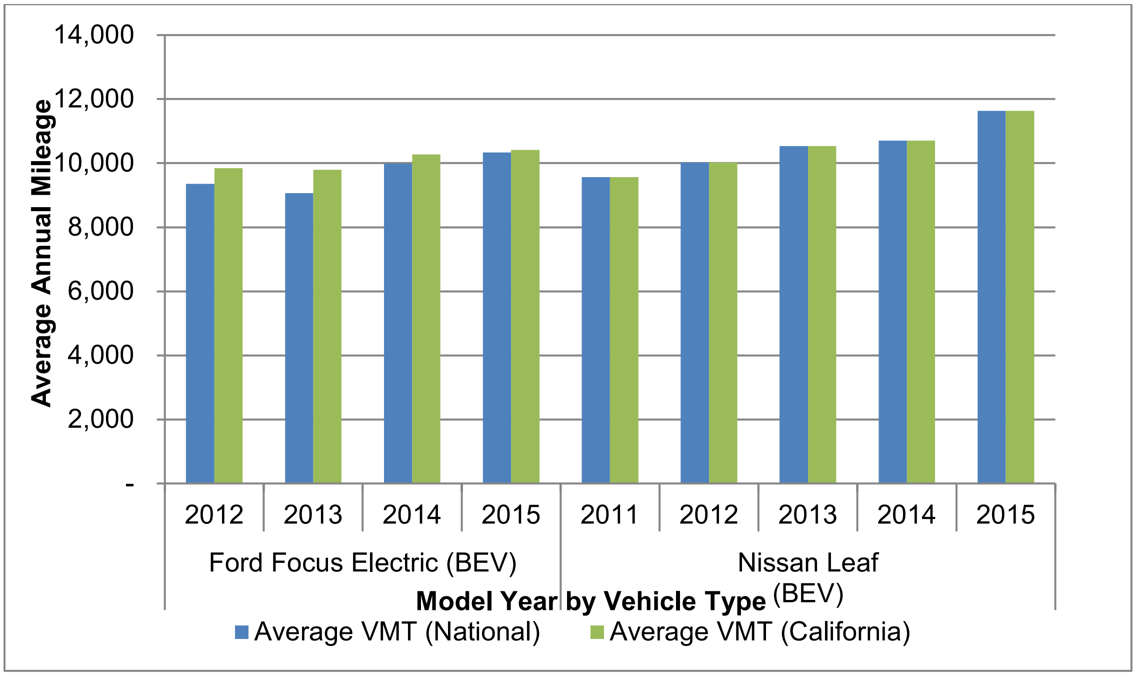
For comparison, vehicles that were designated as California based vehicles[6] are plotted on the same graph. Though varied by model year and vehicle type, the average annual mileage for California based vehicles was approximately 10% higher than the average annual mileage for nationwide vehicles (including those based in California).

Next, ARB staff looked at BEVs and their annual VMT difference with California drivers. Figure 3 shows the average annual mileage by vehicle model per model year for BEVs across the US

[6] See IV Data Overview for description of how vehicle trip records were designated by location.

(including California) and for California only vehicles.[7] Like the PHEVs where VMT increased for newer model year vehicles, so did BEV VMT. However, for BEVs, this means eVMT and zVMT also increased, where, with the exception of the GM Volt, it had remained mostly constant for PHEVs over each model year. Relative to Nissan Leafs, the Ford Focus BEVs in California had only slightly increased average annual mileage. While this may be partially explained by an increase in electric range (~11 miles) by the Nissan Leaf over that timeframe while the Focus BEV's range remained unchanged, it should be noted that several of the increases in VMT from model year to model year in the Leaf were at times when the range did not increase (e.g., 2011-2012, 2014-2015).

Figure 3 - Annual Mileage by Vehicle Type per Model Year for BEVs for US and CA vehicles



Staff was also interested in the effect of lease agreements on driving behavior. Nissan provided such information in their data. Based on sales or lease agreement information, the Nissan Leaf data set provided identifying flags to determine whether a vehicle was privately owned or purchased for a fleet, and whether a vehicle was purchased or leased. If leased, identifying flags were also provided for whether there were 12,000 or 15,000 pre-paid annual miles specified in the lease agreement.

Shown in Table 15, cumulatively, over 97% of the Nissan Leaf vehicles were purchased or leased for private use rather than for use in a commercial fleet. Accordingly, no analysis was attempted to quantify differences in fleet usage relative to privately owned usage.

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[7] Nissan only submitted California data for ARB's analysis. See II.A.ii *FORD* for breakdown of Ford data set by location.

Table 15 - Nissan Leaf Fleet Vehicles vs. Private Vehicles

Model Year	% Fleet Vehicles	% Private Vehicles	% Unknown
2011	4.1%	74.8%	21.1%
2012	2.8%	96.3%	0.9%
2013	1.4%	98.3%	0.3%
2014	0.8%	98.8%	0.4%
2015	2.1%	97.9%	0.0%

Cumulatively, over 71% of the Nissan Leaf vehicles were leased rather than purchased at the initial transaction, as shown in Table 16. For model year 2015, the percentage of vehicles purchased has significantly increased (and the percentage of vehicles leased has significantly decreased). However, the vehicle counts for model year 2015 are very low so additional data would be needed to confirm this initial observation.

Table 16 - Nissan Leaf Leased Vehicles vs. Purchased Vehicles

Model Year	% Leased Vehicles	% Purchased Vehicles	% Unknown
2011	34.4%	50.3%	15.3%
2012	80.2%	19.7%	0.1%
2013	89.0%	11.0%	0.0%
2014	80.6%	19.4%	0.0%
2015	68.0%	32.0%	0.0%

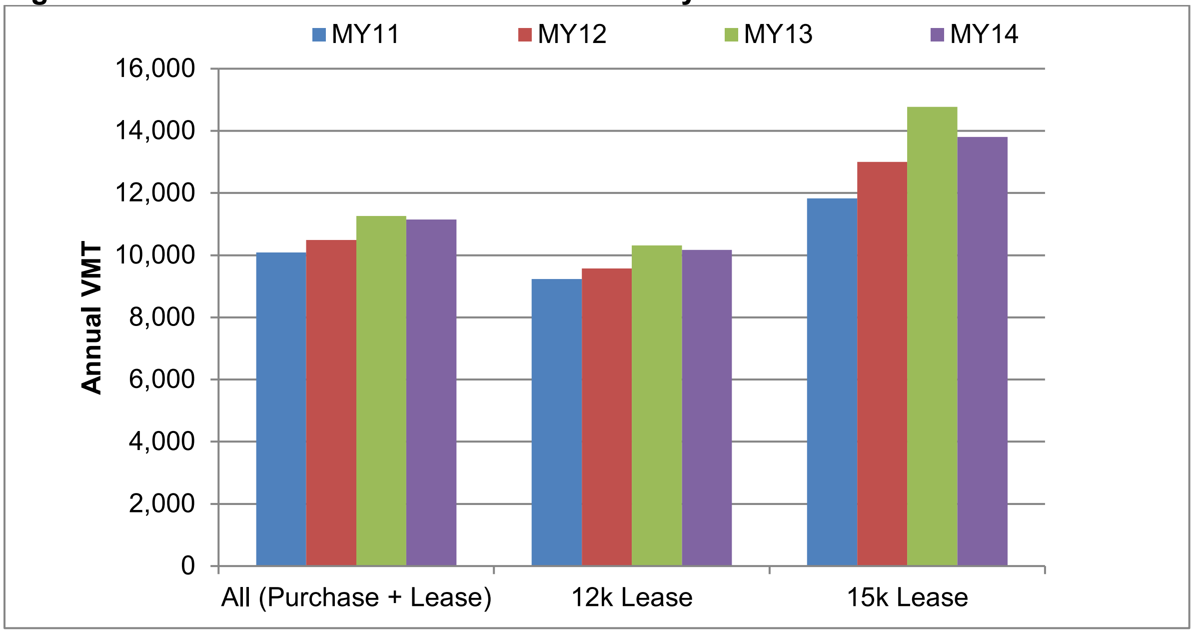
The Nissan Leaf data indicated 8,276 out of a total of 12,194 vehicles were leased (rather than purchased) at the initial transaction. Cumulatively, approximately 67% of the vehicles had lease provisions stipulating 12,000 pre-paid annual miles compared to approximately 24% with 15,000 pre-paid annual miles.

Table 17 - Pre-paid Annual Miles for Leased Nissan Leaf Vehicles

Model Year	% 12,000 pre-paid annual miles	% 15,000 pre-paid annual miles	% Unknown
2011	20.5%	10.8%	3.1%
2012	56.9%	19.8%	3.5%
2013	57.3%	18.6%	13.1%
2014	62,3%	18.0%	0.3%
2015	54.6%	13.4%	0.0%

While the mileage caps for leases do not physically limit additional vehicle operation, some correlation of the mileage cap to the annual VMT would be expected. And as shown in Figure 4, when comparing the annual VMT of all vehicles in the sample to vehicles leased with a 12k or 15k mileage cap, the average VMT is indeed shorter for vehicles with 12k leases and longer for vehicles with 15k leases. Given the selection of the lease terms during the initial purchase of the car, it would be expected for drivers with lower annual VMT needs to select the lower terms and those with higher needs to select a higher mileage cap. Nonetheless, the data suggests that the vehicles themselves are capable of meeting higher annual VMT demands despite their electric range or charging limitations.

Figure 4 - Nissan Leaf Initial Year Annual Miles by Model Year and Lease Terms



IV.C. Average monthly plots for percent eVMT and zVMT, and e-trips for PHEVs

Monthly averages for usage shows seasonal variability which cannot be shown in annual averages. Staff plotted monthly averages for the Ford, Honda, Toyota, and General Motors PHEV data sets as shown in Figure 5, 6, 7, 8, 9, and 10. For the BEV vehicles (BMW i3, Ford Focus EV, Honda Fit EV, Nissan Leaf, and Tesla Model S), the %eVMT, zVMT, and e-Trips would all be 100%, and therefore are not included in these results. The Ford data set provided truncated GPS data to determine which vehicles had the majority of their trips within California so separate California specific plots were also provided in the following results.

PHEV mean %eVMT, %zVMT, and %e-Trip results were based on data that was filtered to only include vehicles with more than 24 consecutive days of trip data and cumulative VMT calculated from individual trips that were within 85% of the VMT calculated from odometer change.[8] For the Honda Accord PHEV, no odometer data was provided so filtering was limited to vehicles with more than 24 days of trip data.

For the Ford PHEVs, Figure 5 through Figure 8 show relatively consistent monthly trends with an observable decrease in electric vehicle usage in the winter months. Generally, all three metrics follow the same trends although percent e-Trips shows a slightly more pronounced drop in winter months which may be due to initial short periods of engine on operation to meet cabin

[8] Filtering the data sets using alternative methods could provide different results.

heating and defrost demands. As could be expected, the seasonal impact is substantially larger in the nationwide sample than in the California only sample.

Figure 5 - Average Monthly %eVMT, %zVMT & %e-Trips for Ford C-Max Vehicles - All Trips

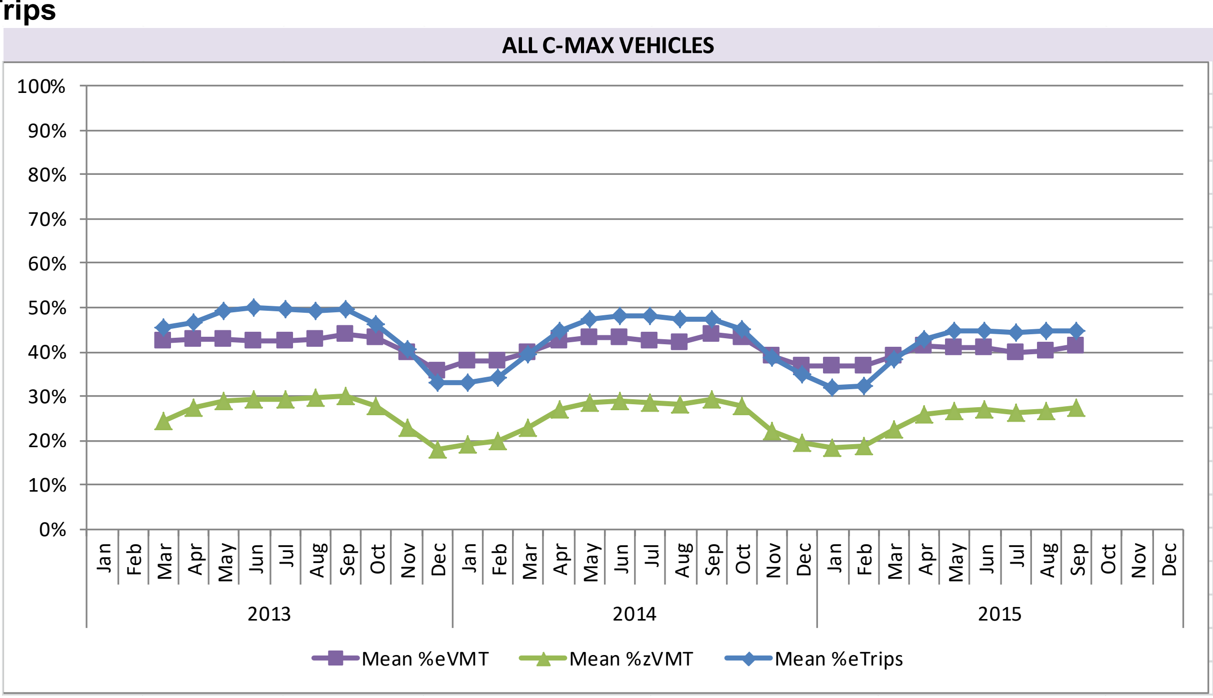


Figure 6 - Average Monthly %eVMT, %zVMT & %e-Trips for Ford C-Max Vehicles - CA Trips

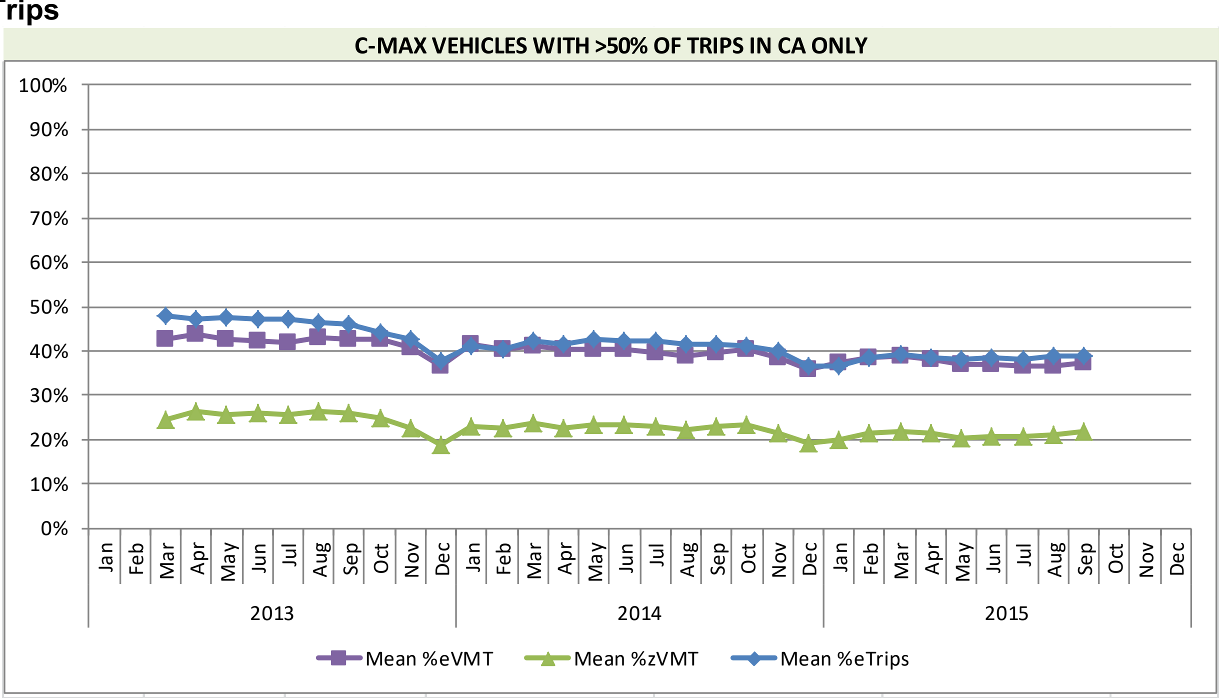


Figure 7 - Average Monthly %eVMT, %zVMT & %e-Trips for Ford Fusion Vehicles - All Trips

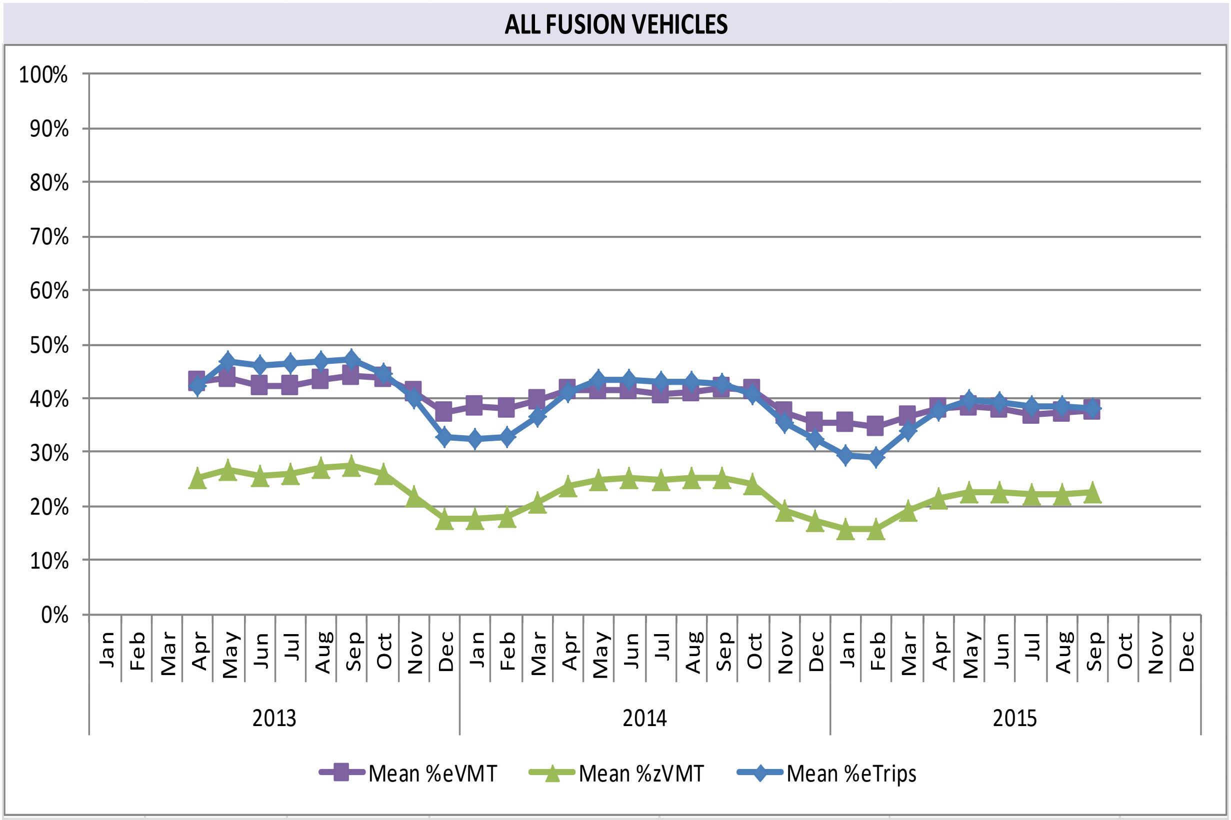
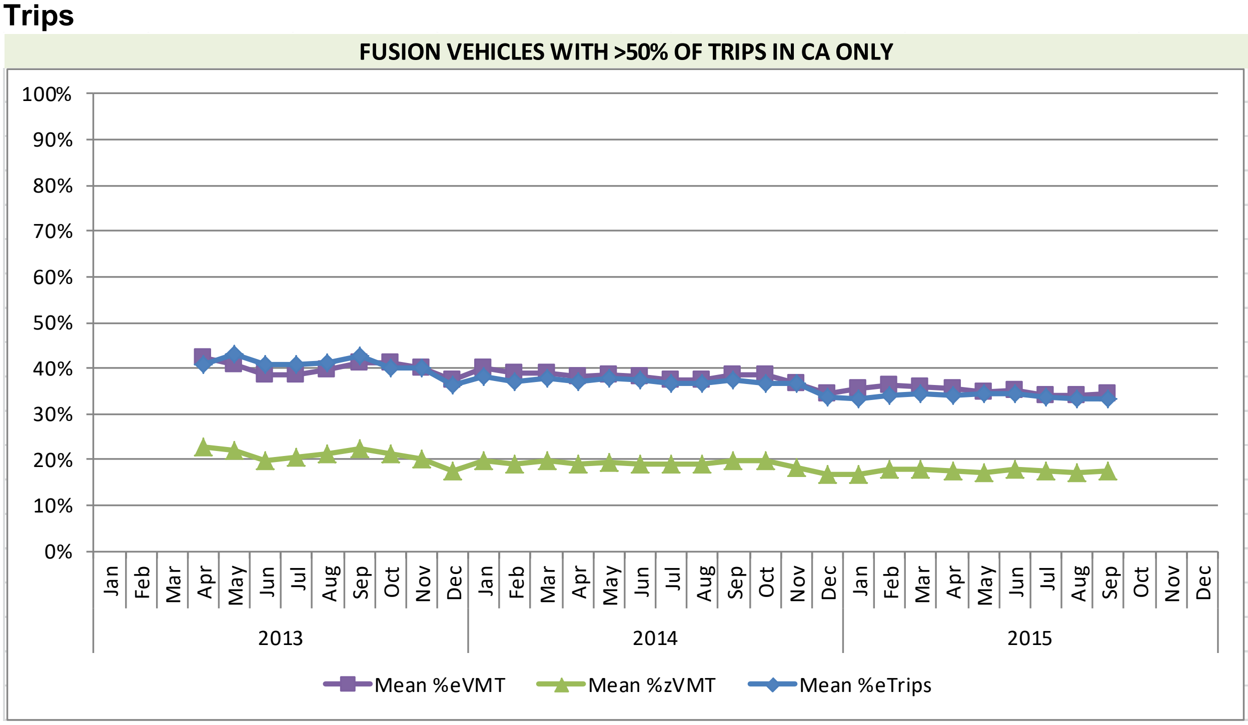


Figure 8 - Average Monthly %eVMT, %zVMT & %e-Trips for Ford Fusion Vehicles - CA Trips



For the GM Volt vehicles, the monthly data also shows a seasonal impact with a small drop in electric vehicle usage during the winter months. While the magnitude of the impact on the nationwide sample appears to be smaller than observed on the Ford PHEVs, the California only data follows similar trends as the Ford data with a very small seasonal impact.

Figure 9 - Average Monthly %eVMT, %zVMT & %e-Trips for GM Volt Vehicles - All Trips

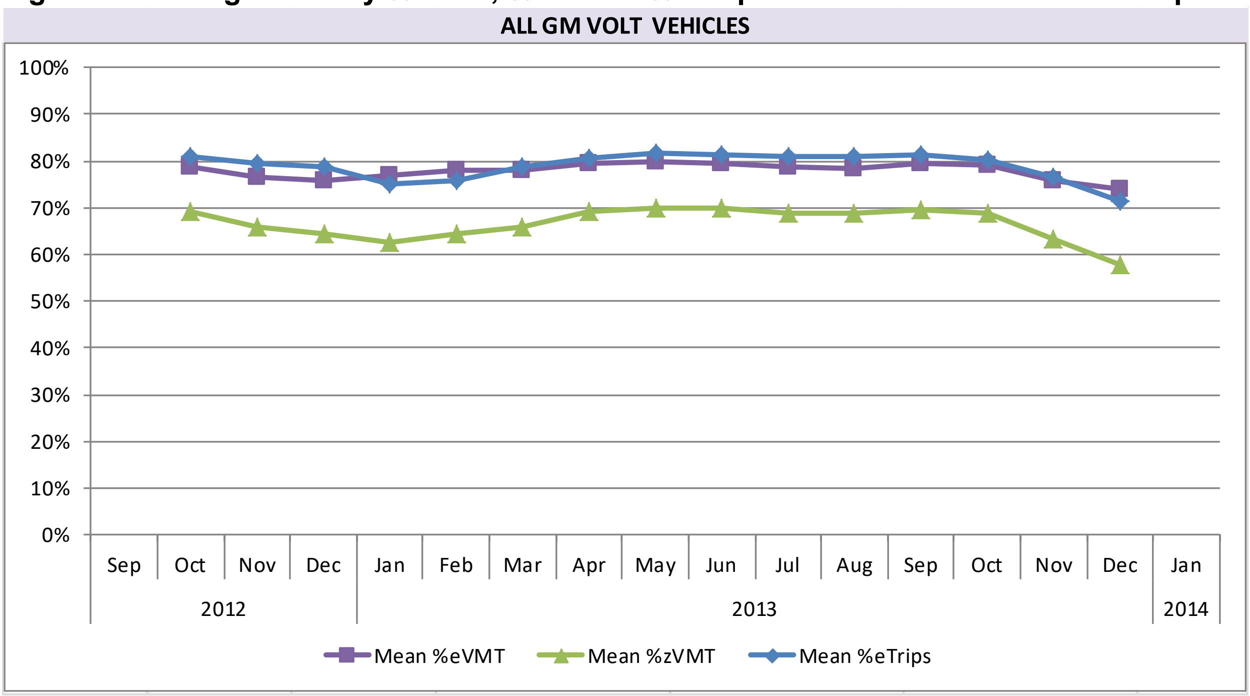
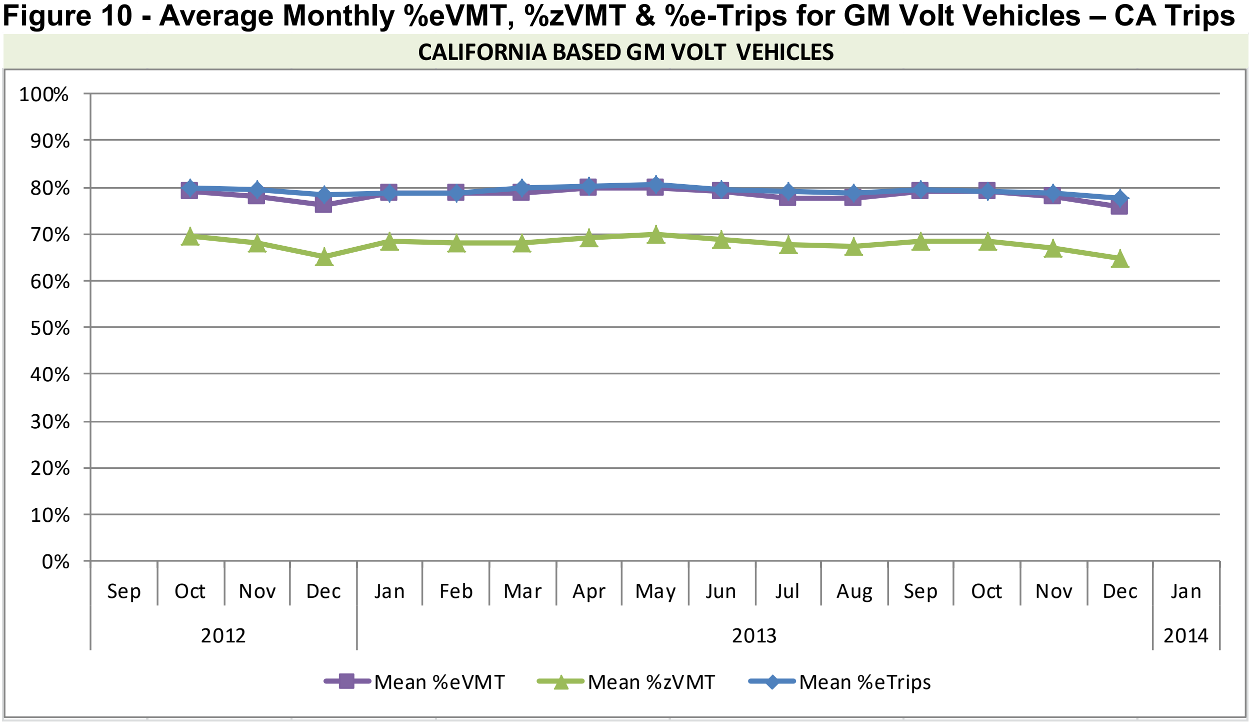


Figure 10 - Average Monthly %eVMT, %zVMT & %e-Trips for GM Volt Vehicles – CA Trips



For both the Honda and Toyota PHEVs in Figure 11 and Figure 12, similar but smaller seasonal impacts were observed. The Honda dataset, while not limited to California cars, is predominantly California cars and only had one winter period during the data sample. The Toyota data was nationwide and did show a slightly larger seasonal impact than the Honda but still a relatively minor change in vehicle usage.

Figure 11 - Average Monthly %eVMT, %zVMT & %e-Trips for Honda Accord Vehicles - All Trips

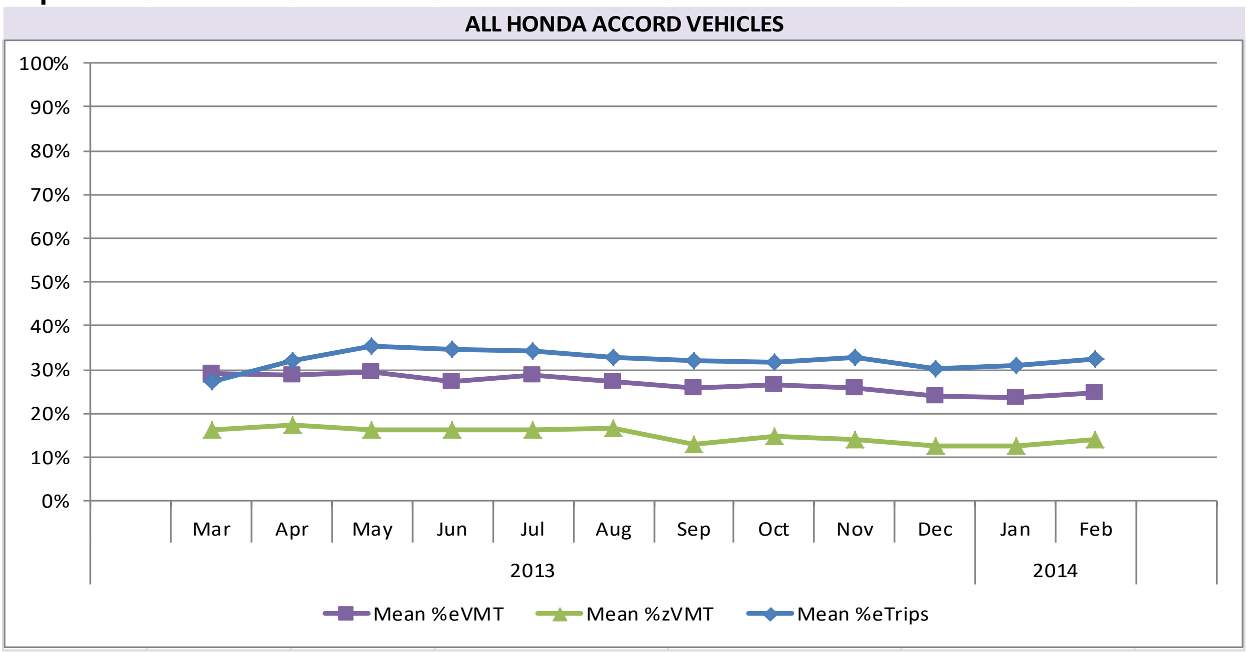
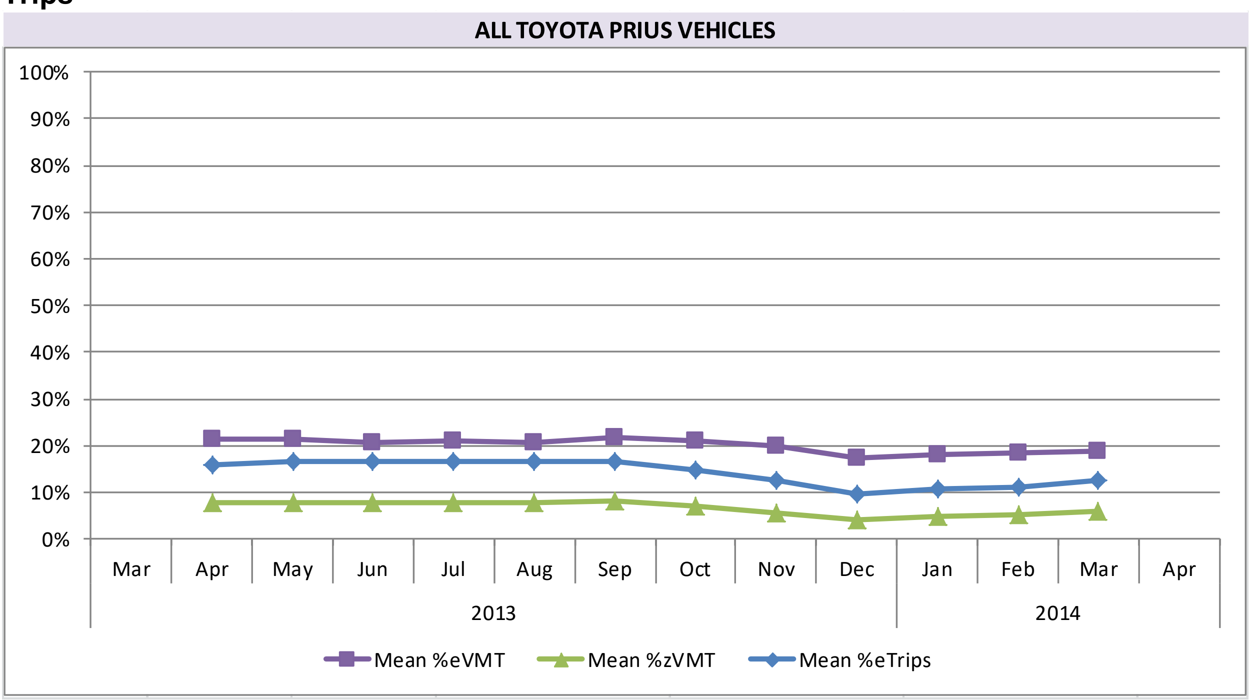


Figure 12 - Average Monthly %eVMT, %zVMT & %e-Trips for Toyota Prius Vehicles - All Trips

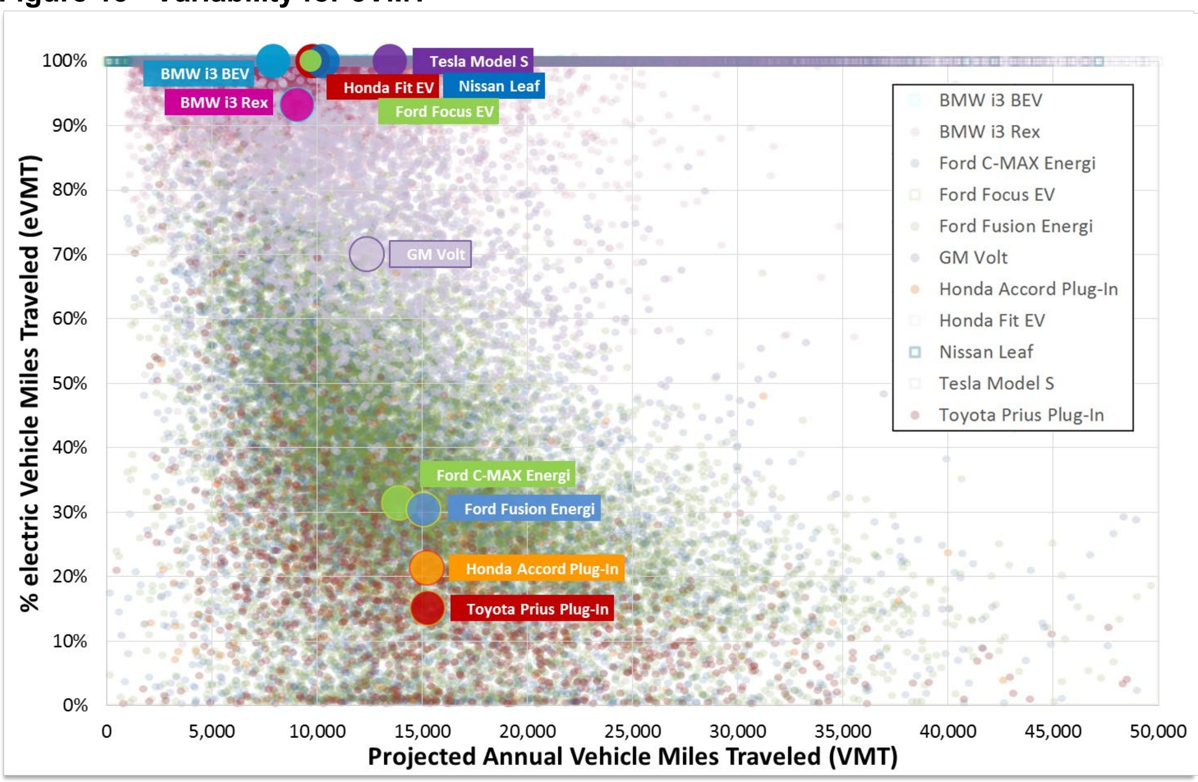


In general, the results indicate that electric vehicle usage varies across different seasons with the highest eVMT occurring during summer months and the lowest occurring during the holiday season months (Nov - Jan). However, while electric usage does vary, it does not appear to vary significantly, and varies to an even smaller degree in California-based vehicles.

IV.D. Analysis of factors affecting eVMT

While most of the analysis shown is comparing the usage across different PHEV models, staff also analyzed data within a PHEV model to understand some of the factors that may be influencing the observed performance. In Figure 13 below, the small dots reflect the eVMT of each individual car in the sample while the large dots show the average eVMT for that PHEV model. From the figure, it is apparent that there is significant variation as to the calculated eVMT for individual vehicles within the models. While not shown, figures showing absolute eVMT (miles) rather than eVMT percent or showing zVMT rather than eVMT, look similar in terms of substantial variability among the individual vehicles within a model. The figure also shows BEVs, which are the dense line along the y-axis value of 100% eVMT. This reinforces that substantial variability also occurs in individual BEV users with respect to how many annual miles they drive. With BEVs, however, all of the miles that are traveled are grid-powered electric miles.

Figure 13 - Variability for eVMT



From the data received from OEMs, the Ford PHEV data represented the largest set of detailed PHEV data from actual customer cars. The Ford data was analyzed to try and determine if there were clear factors or trends observable that were common among the drivers that were achieving higher eVMT than others. First, staff compared the eVMT, both on a percent eVMT and an absolute eVMT annual miles basis, to the average number of trips taken per day for each vehicle. Figure 14 and Figure 15 show that there was no identifiable correlation between the average number of trips taken per day and the observed eVMT for the individual vehicle.

Figure 15 - Percent eVMT vs. trips/day

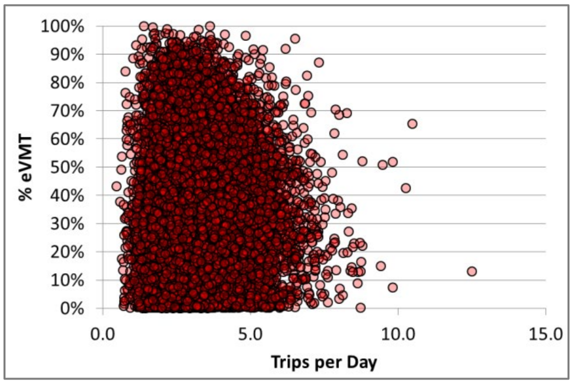
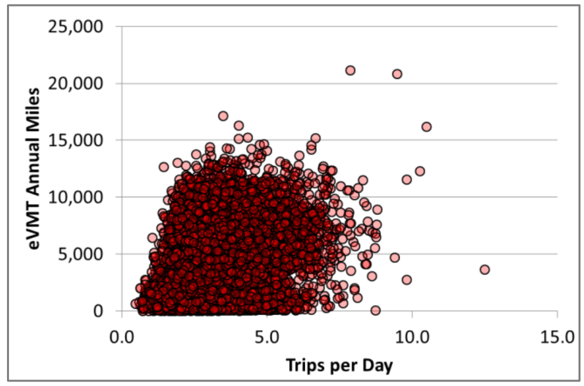


Figure 14 - Absolute eVMT vs. trips/day



When looking at average trip length (miles) versus percent eVMT (Figure 16 and 17), a slight trend appears in the direction that would be expected. That is, the longer the average trip length, the lower the observed eVMT percentage. However, this trend is not apparent when looking at percent eVMT rather than absolute eVMT. For vehicles with shorter average trip lengths, there is still considerable variation spanning the entire range from 0% to 100% in eVMT percentage.

Figure 17 - Percent eVMT vs. Trip Length

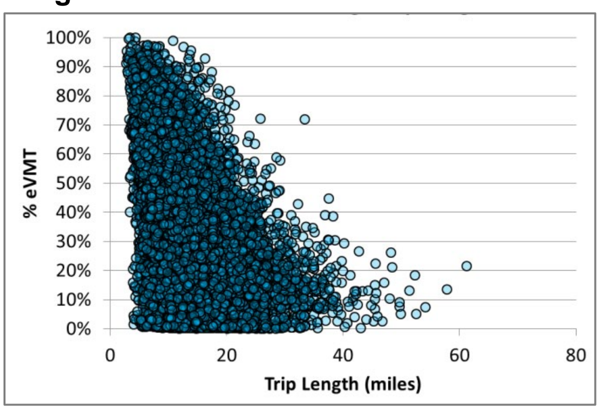
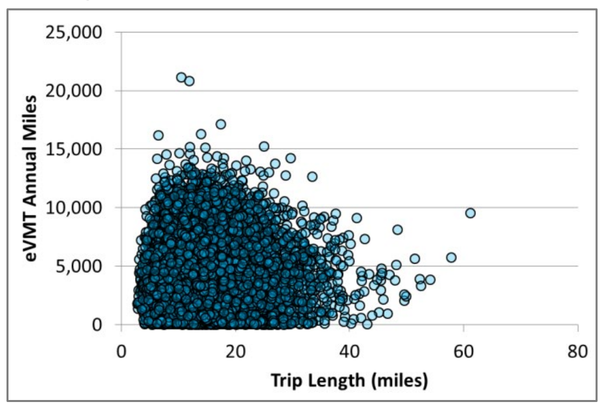


Figure 16 - Absolute eVMT vs. Trip Length



A different observation is made when looking at average daily VMT versus eVMT (Figure 18 and Figure 19). For eVMT percentage, the data shows a similar trend to the previous figures such that the higher the average daily miles traveled, the lower the eVMT percentage as well as significant variation from 0%-100% eVMT for vehicles averaging the fewest miles per day. In the absolute eVMT figure, however, the opposite trend is observed with an increase in daily miles traveled correlating slightly to an increase in absolute eVMT.

Figure 19 - Percent eVMT vs. Daily VMT

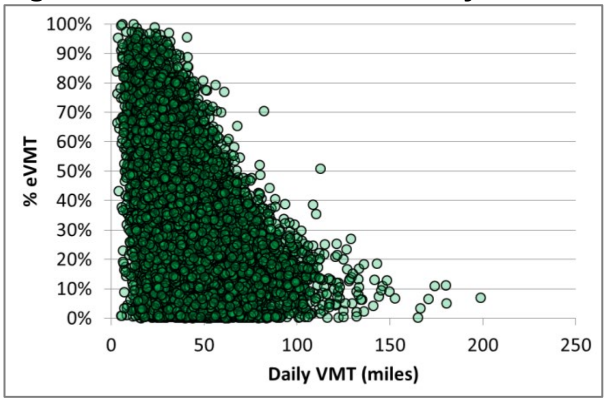
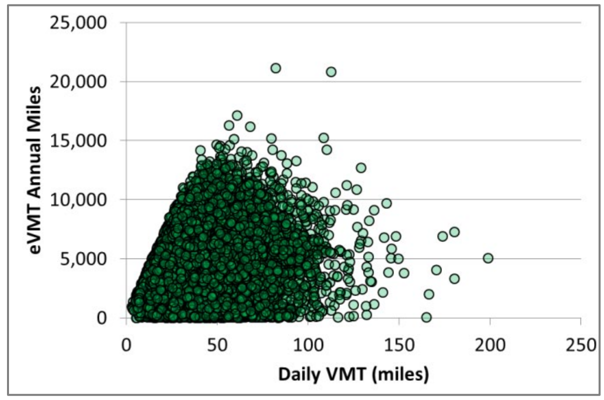


Figure 18 - Absolute eVMT vs. Daily VMT



Staff also analyzed charging habits to see if a correlation was apparent to calculated eVMT. In Figures 20 and 21 below, the average number of charging events per day was compared to percent and absolute eVMT. From the staff's analysis, this parameter appeared to have the strongest correlation to eVMT, especially when looking at absolute eVMT. Consistent with what would be expected, more frequent charging measured as average number of charge events per day generally correlates to higher eVMT. The data was also analyzed versus the number of Level 2 charging events per day. A similar, but slightly weaker, trend was observed indicating increased Level 2 charge events per day correlated to higher eVMT. Further analysis is needed to determine if the higher charging events per day are a result of increased usage of 'away from home' charging (e.g., public infrastructure, workplace charging) or from vehicle owners who are using home charging more frequently (e.g., plugging in at home between errands or other daily trips).

Figure 21 - Percent eVMT vs. Charge Events/day

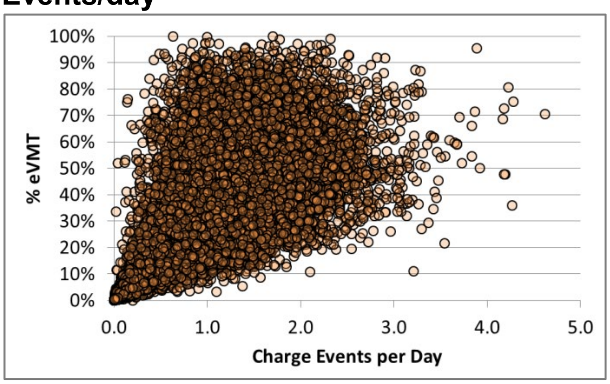
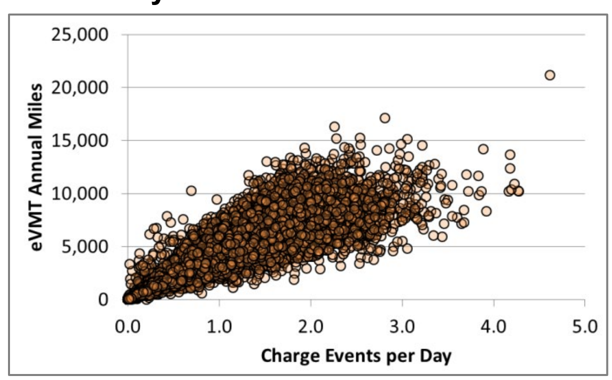


Figure 20 - Absolute eVMT vs. Charge Events/day



Regarding charging behavior, the relative usage of Level 2 charging was also analyzed to look for an influence on eVMT. Figure 22 and Figure 23 below show eVMT versus the percentage of charging events that used Level 2 charging to see if using the faster and higher power charging equipment for a larger share of the charging events would correlate with higher eVMT. For these Ford PHEVs, however, there is no identifiable trend in either percent or absolute eVMT for vehicles using Level 2 charging for a larger share of the total charging events.

Figure 23 - Percent eVMT vs. Level 2 Charge Events/day

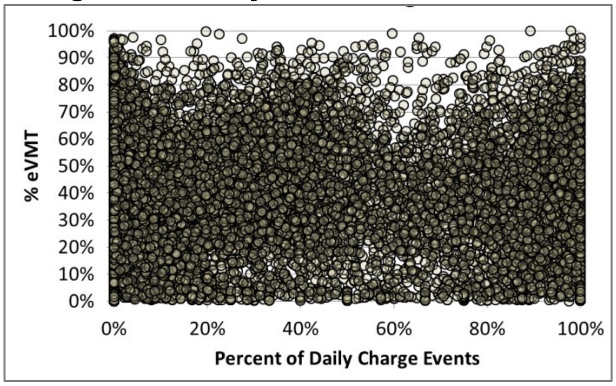
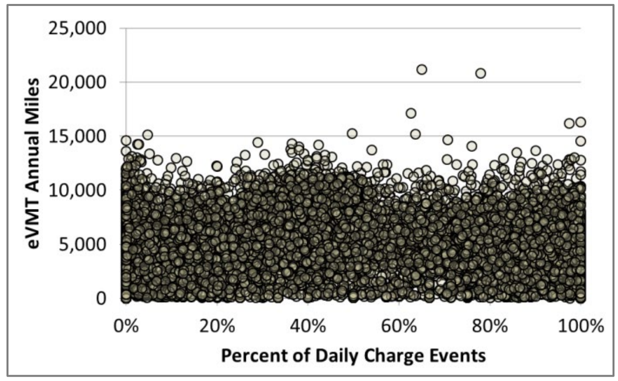


Figure 22 - Absolute eVMT vs. Level 2 Charge Events/day



V. Charge Results

V.A. Data provided

All the manufacturers provided various levels of charge data and generally fall into one of three categories. The first category is those that provided charge, charge type, and charge location information. Nissan, Figure 24 to Figure 31, and Ford, Figure 32 to Figure 34, provided that data and the figures show the distribution of charge events. The second category is manufacturers who provided limited charge event data. This included data for the Honda Fit, Figure 35 to Figure 37, and for the GM Volt, Figure 38. The last category is manufacturers who did not provide any charge event information and are excluded from this analysis. BMW and Tesla did not provide any charge data. The Honda Accord PHEV charge data also has no date and time, no charging type, and no location information. The Toyota Prius PHEV charge data did not provide any charging type or location information.

V.B. Charging capability

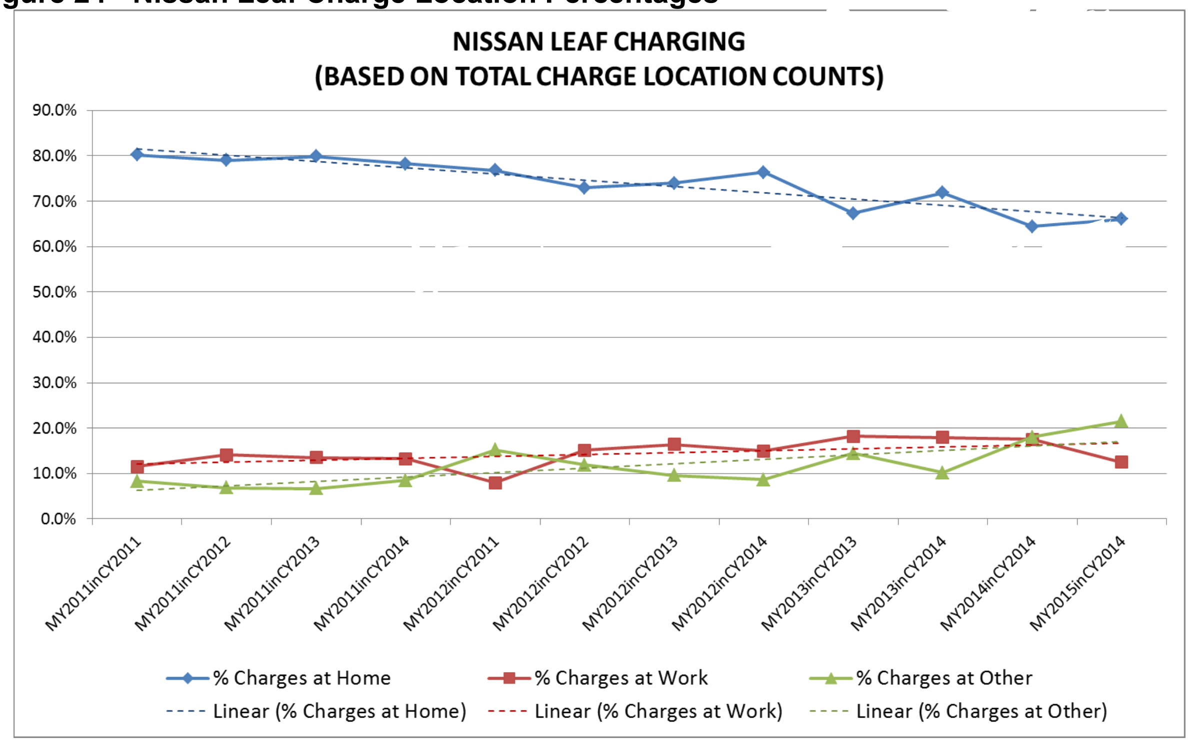
The Ford Fusion Energi and C-MAX Energi have an all-electric label range of 19 miles, and can be fully charged on a 240 Volt Level 2 charger in approximately 2.5 hours, or 7 hours on a 120 Volt Level 1 charger. The Ford Focus EV has a label range of 76 miles and can be fully charged in 3.6 hours from a Level 2 charger, or approximately 18-20 hours on a Level 1 charger. Each of these vehicles is sold with a Level 1 convenience charge cord which can charge the vehicle from any standard 120V household outlet.

V.B.1. Nissan Plots

The next set of graphs provide data regarding the Nissan Leaf charging locations, charge type, purchased versus leased vehicles, and fleet versus private vehicles. Later in the section, the charge information is then plotted against average VMT and eVMT for the Nissan Leafs.

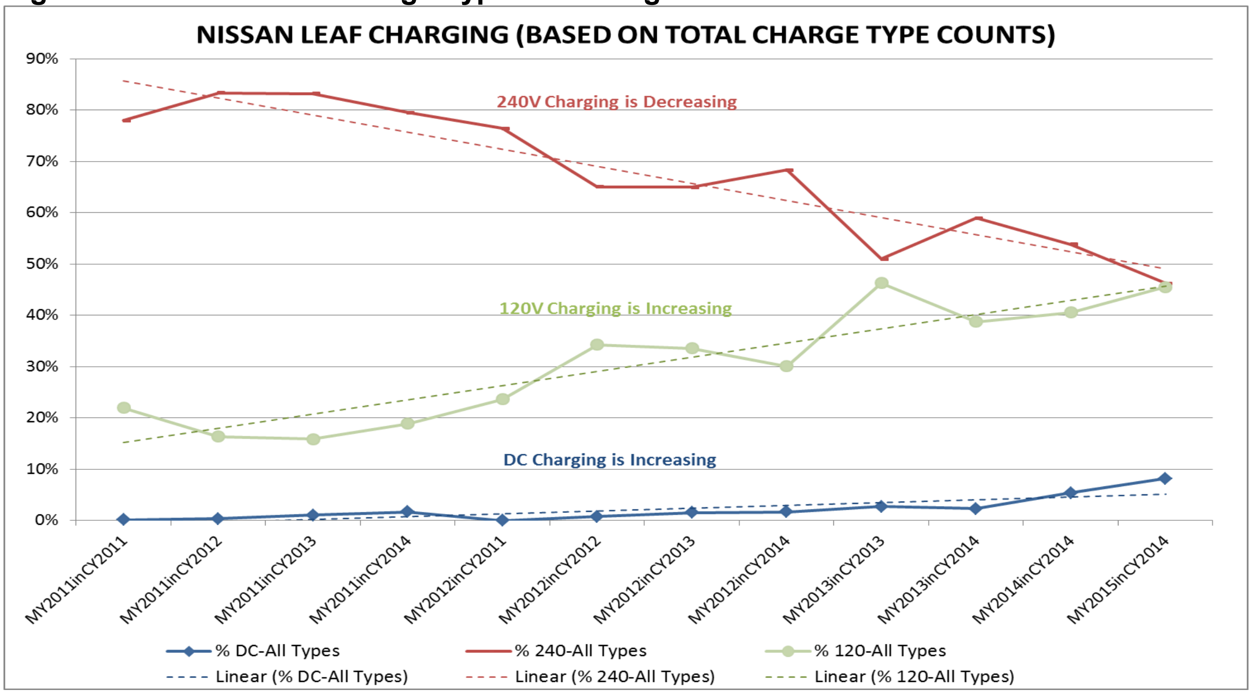
The percentage of Nissan Leaf charge events taking place at home has decreased approximately 15% from the 2011 model year to the 2015 model year as the percentage of charge events at work and other locations has been increasing. This trend can be seen in Figure 24.

Figure 24 - Nissan Leaf Charge Location Percentages



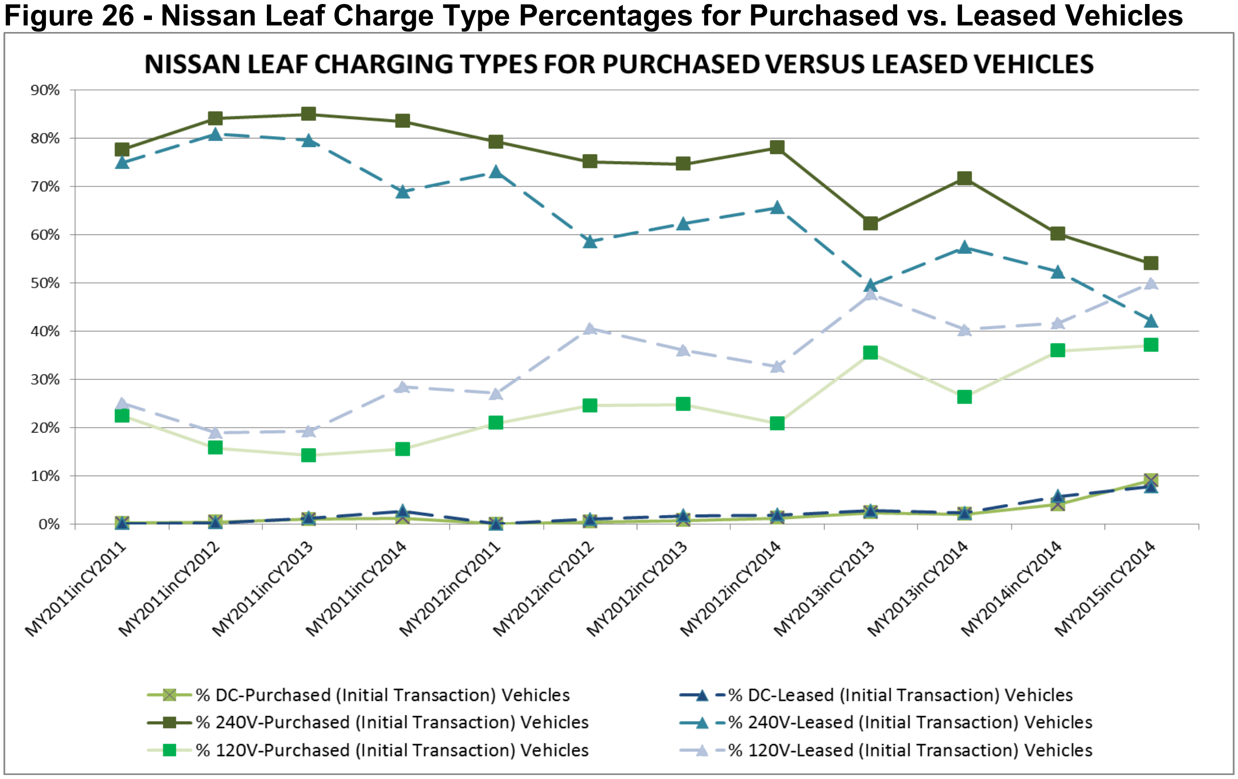
The percentage of Nissan Leaf charge events occurring using Level 2 (240V) has decreased over 30% as the charge events at Level 1 (120V) have increased significantly and the DC charge events have increased slightly as seen in Figure 25.

Figure 25 - Nissan Leaf Charge Type Percentages



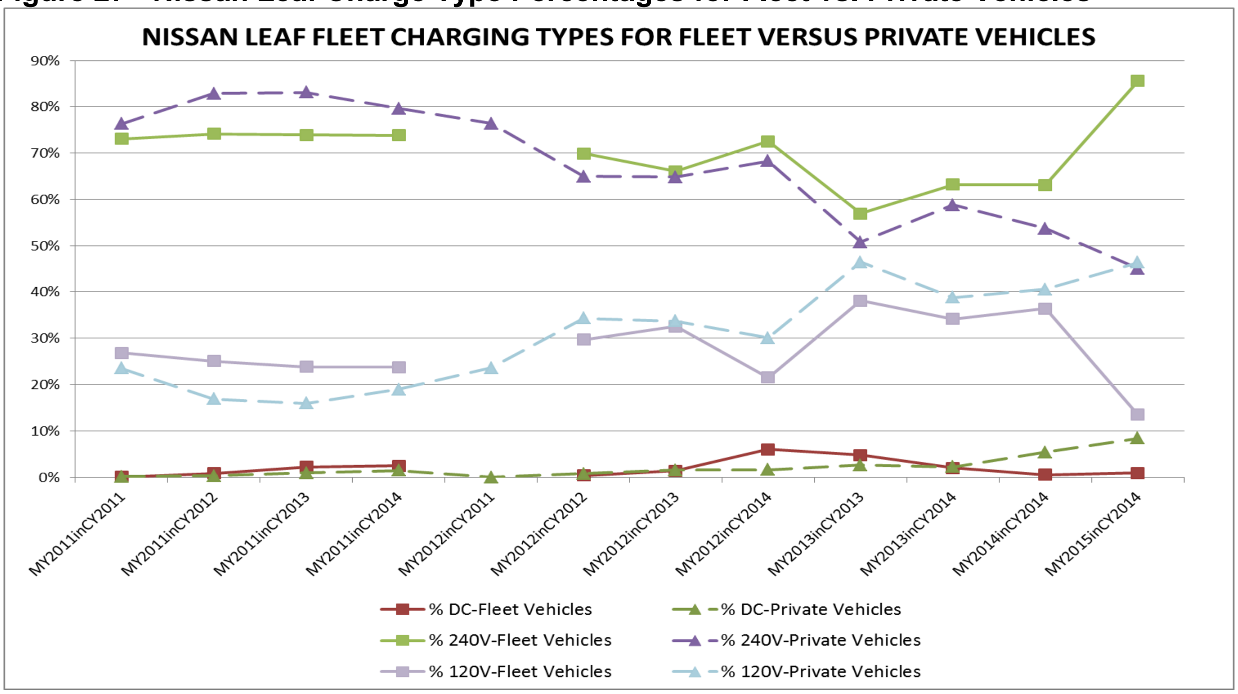
The Nissan Leaf vehicles that were purchased rather than leased show slightly higher rates of Level 2 charging events and lower rates of Level 1 charging events compared to the vehicles that were leased. This trend in seen in Figure 26.

Figure 26 - Nissan Leaf Charge Type Percentages for Purchased vs. Leased Vehicles



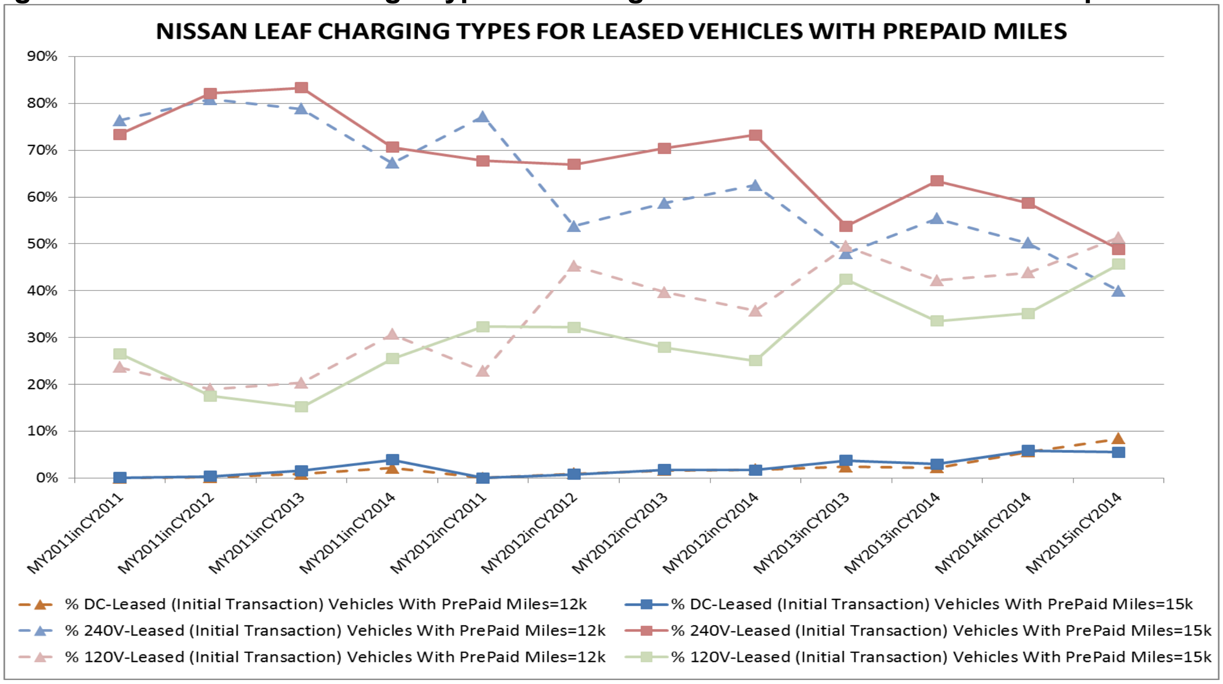
Nissan Leaf vehicles that were purchased as fleet vehicles did not show much of a difference in the charging types though the Level 2 rates were slightly higher and the Level 1 were slightly lower than the vehicles purchased for private usage. However, the percentage of cars identified as fleet vehicles was a very small percentage of the total vehicles. This can be seen in Figure 27. No definitive conclusions are drawn here but the data is presented in Figure 27.

Figure 27 - Nissan Leaf Charge Type Percentages for Fleet vs. Private Vehicles



The Nissan Leaf leased vehicles with 12,000 pre-paid miles in the lease agreements showed slightly higher rates of charging events at Level 1 and less at Level 2 relative to those vehicles that had been leased with a pre-paid 15,000 miles as seen in Figure 28.

Figure 28 - Nissan Leaf Charge Type Percentages for Leased Vehicles with Prepaid Miles



Looking at overall trends for the Nissan Leaf in Figure 29, the Nissan Leaf Level 1 charging event rates generally increased over time and model year for charging at home and decreased over time for charging at work or other locations. The Level 2 charging event rates showed the opposite trend (decreasing at home/increasing at work and other locations). This information is important to plan infrastructure and for marketing the vehicles. However, this trend might change as stronger ZEVs come to the market with a higher all-electric range.

Figure 29 - Nissan Leaf Charge Location & Type Percentages

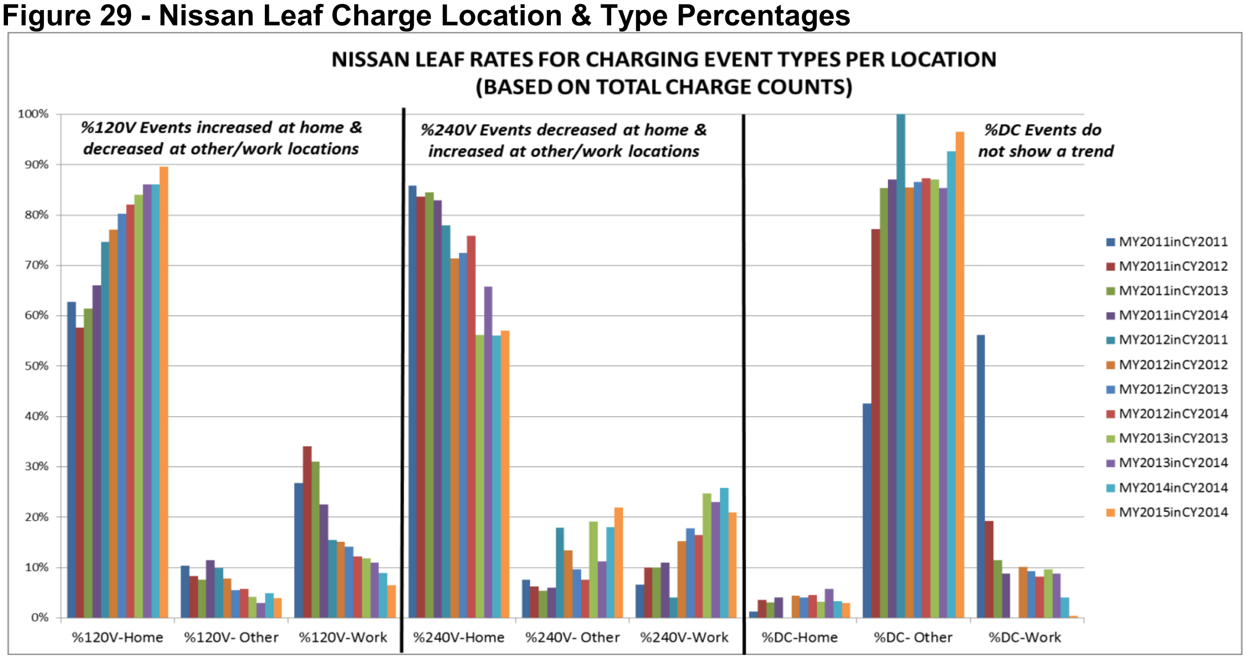


Figure 30 shows monthly average VMT trends for Nissan Leaf vehicles both with and without any DCFC events. *NOTE: Nissan Leaf has 100% eVMT/zVMT/eTrips, average VMT is needed to show more miles with DCFC.*

Figure 30 - Nissan Leaf Average VMT by DCFC events

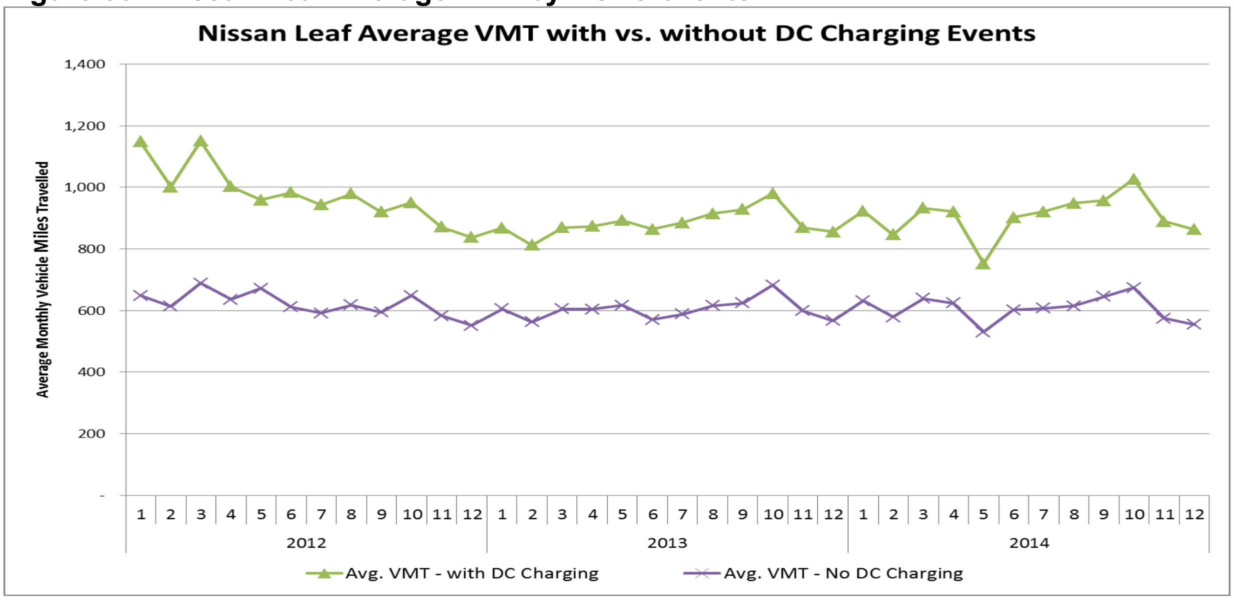
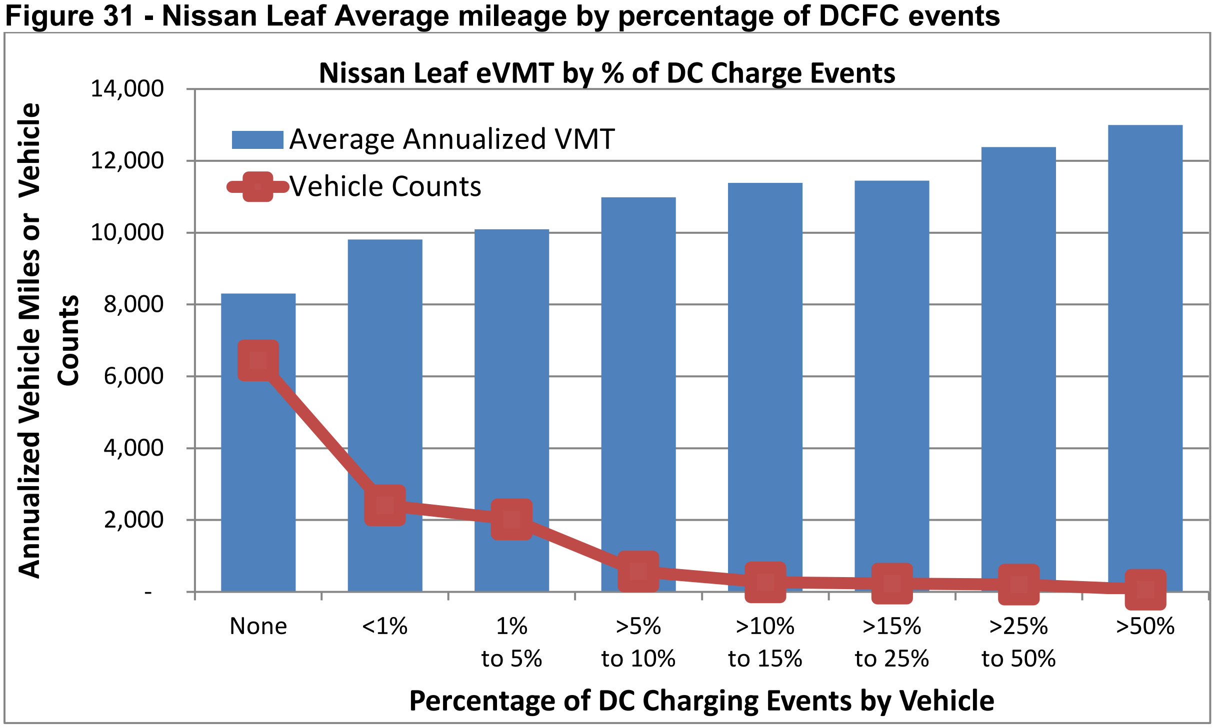


Figure 31 shows annualized average mileage trends for Nissan Leaf vehicles by the percentage of DCFC events. Since the vehicle number is small, few meaningful conclusions can be made from these data. However, it appears that DCFC does have some positive effect on the average monthly VMT for Nissan Leafs in this data sample.

Figure 31 - Nissan Leaf Average mileage by percentage of DCFC events

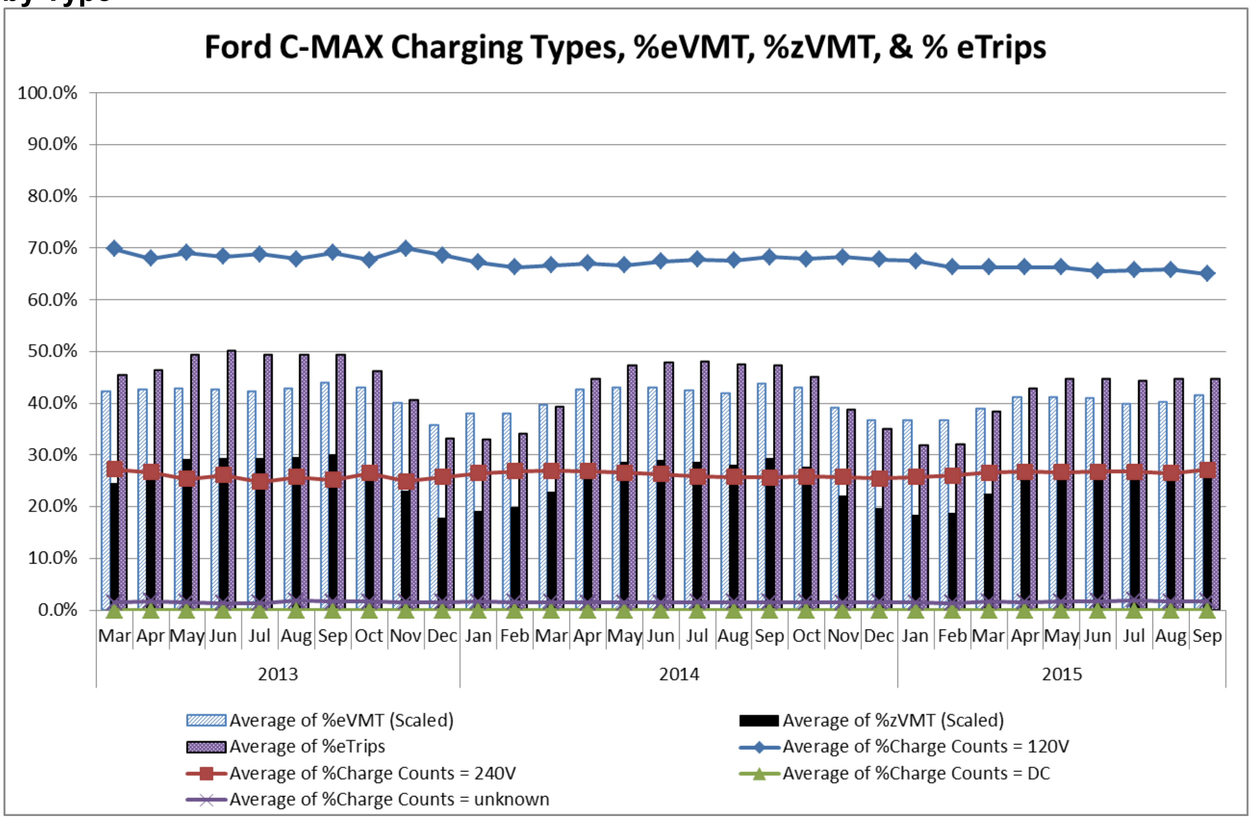


V.B.2. Ford Plots

The next set of plots show charge events with type of charging and average monthly trends for the Ford dataset to evaluate if there are seasonal variations in charge events and %eVMT, %zVMT and %eTrips data.

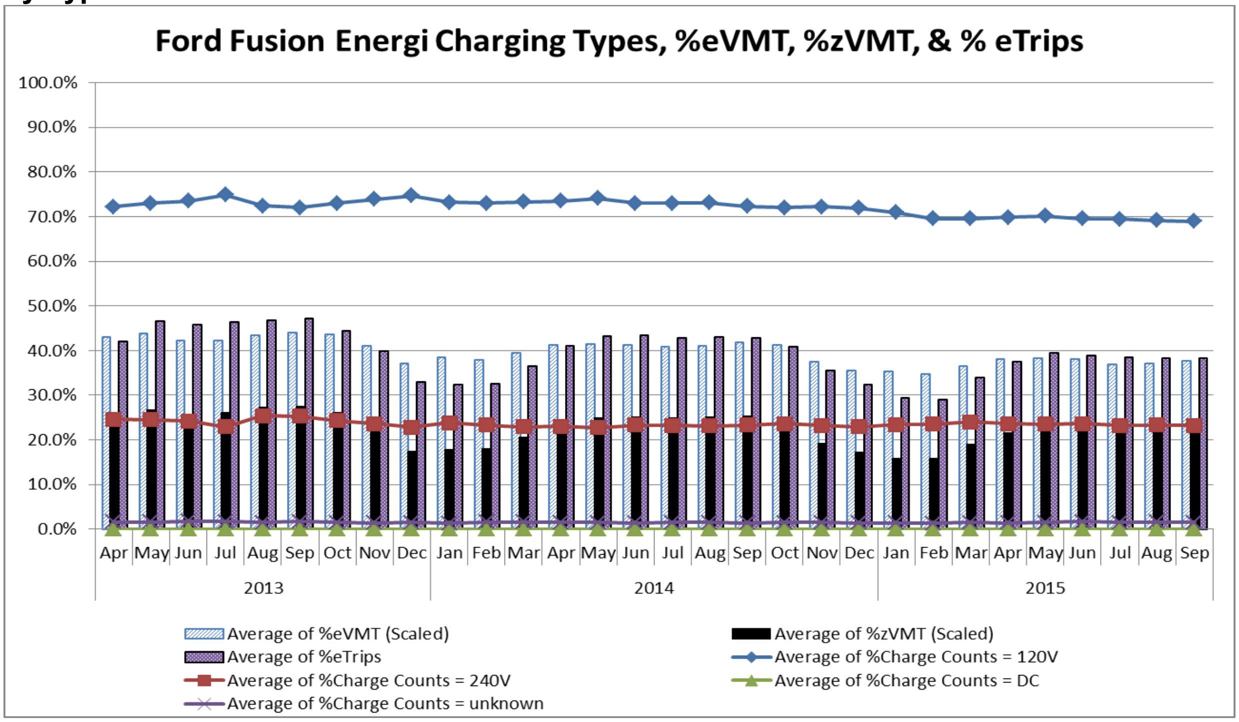
The percentage of charges by type (240V, 120V, or DC) do not show changes over time for the Ford C-Max vehicle. As shown in Figure 32, the changes in the percentages of eVMT, zVMT and eTrips appear to show seasonal variations with decreased activity in the winter months (unrelated to charging types).

Figure 32 - Ford C-Max Average Monthly %eVMT, %zVMT, %eTrips and % Charge Counts by Type



The Ford Fusion Energy data, illustrated in Figure 33, showed very similar trends to the C-Max vehicles.

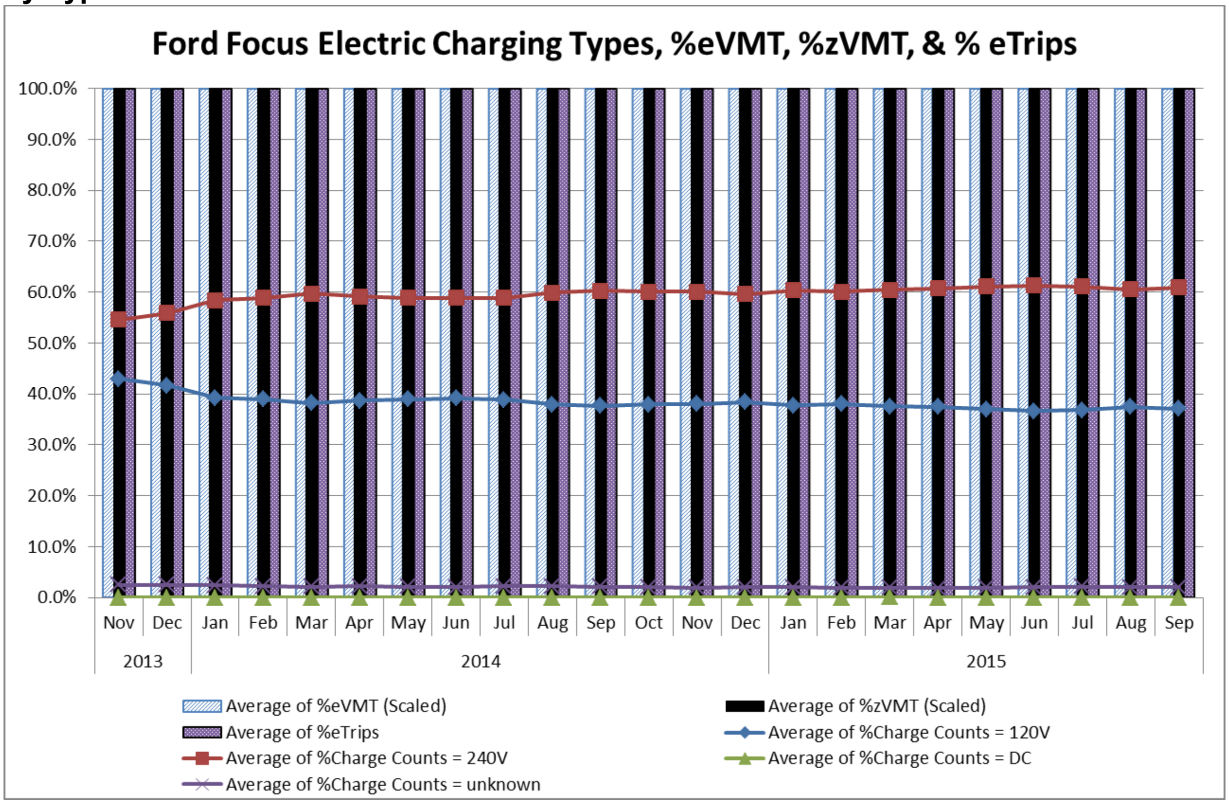
Figure 33 - Ford Fusion Average Monthly %eVMT, %zVMT, %eTrips and % Charge Counts by Type



As shown in Figure 34, the Ford Focus BEV also showed a steady trend in the types of charging over time. However, compared to the Ford PHEVs, the Ford BEV showed a significantly higher percentage of charging at Level 2 and significantly less at Level 1. However, there are no seasonal trends seen for charging activity.

In summary, the changes in the percentages of eVMT, zVMT and eTrips appear to show seasonal variations with decreased activity in the winter months; however, this is unrelated to charging types for Ford PHEVs (C-Max, and Fusion Energi) and the Ford Focus Electric.

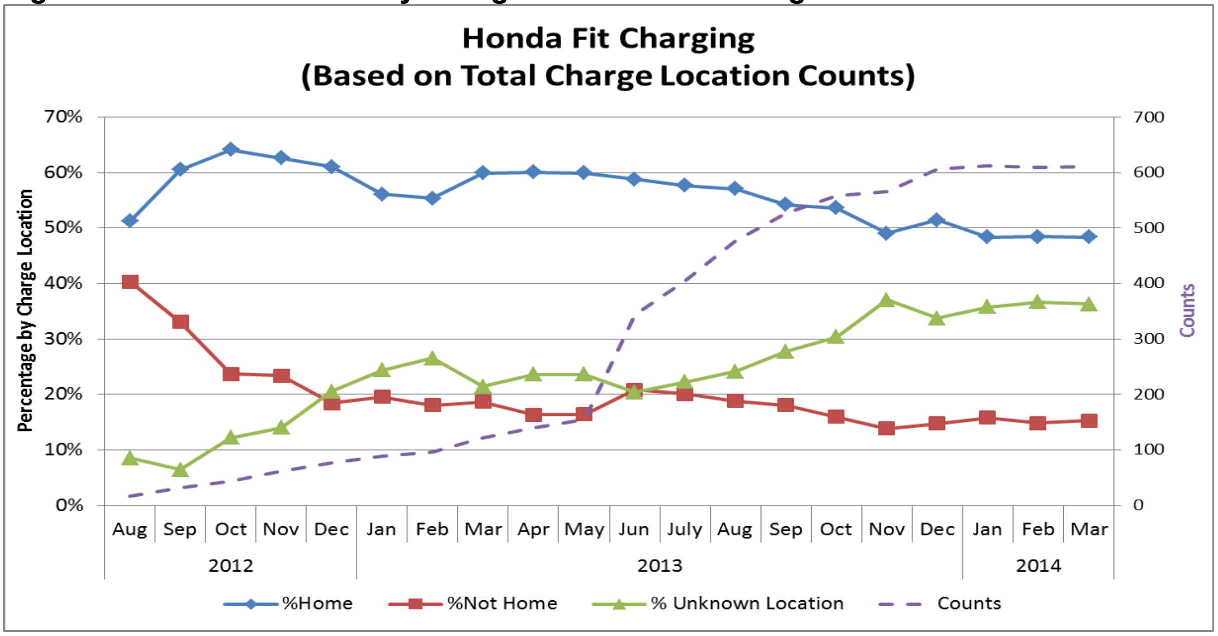
Figure 34 - Ford Focus Average Monthly %eVMT, %zVMT, %eTrips and % Charge Counts by Type



V.B.3. Honda Plots

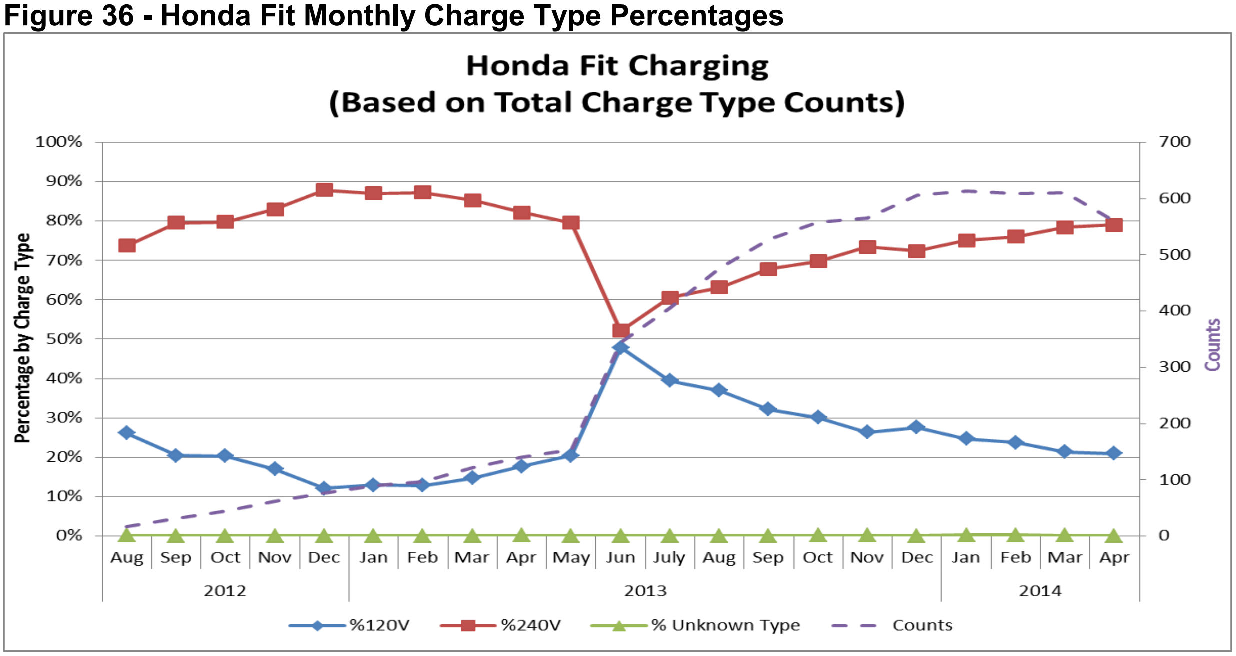
The next set of plots show the data for the Honda Fit. The charge location information provided for the Honda Fit vehicles shows an increasing percentage of unknown charging locations over time. This makes it difficult to determine if changes over time reflect an actual change, such as a decreasing percentage of home charging, or whether that was due to more home charge events being categorized as unknown charging locations as the recorded charge counts increased. The data is graphed in Figure 35.

Figure 35 - Honda Fit Monthly Charge Location Percentages



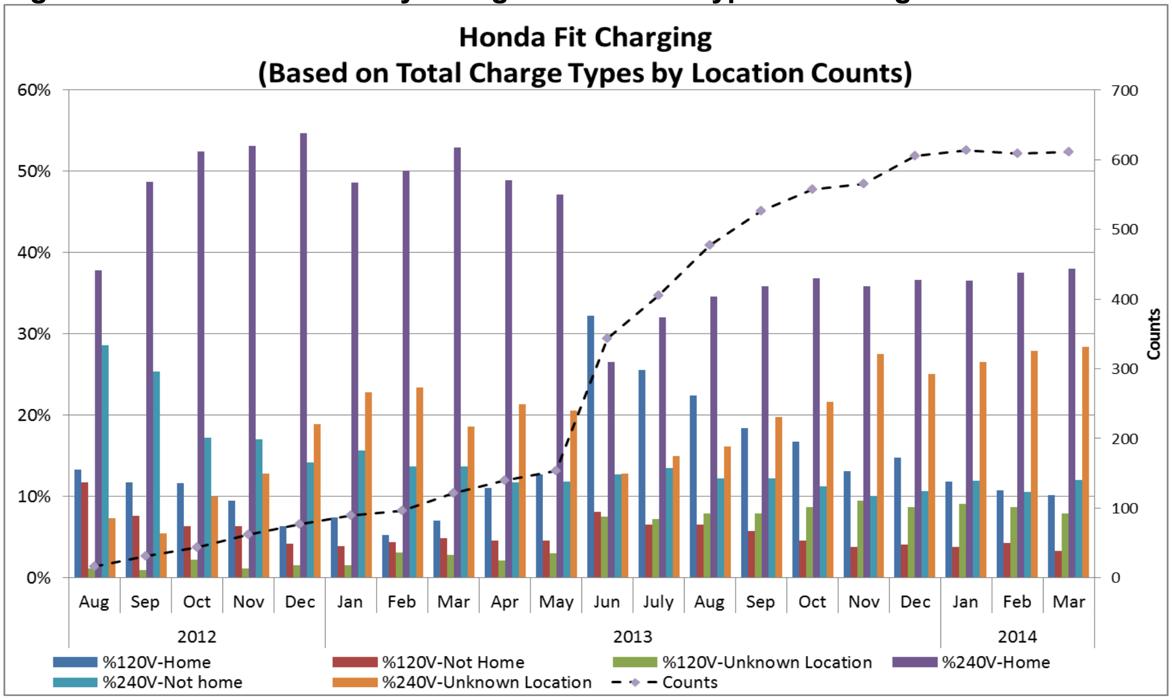
The recorded charge types for the Honda Fit did not show a similar trend in that the unknown charge type percentages were extremely low. However, as the recorded charge counts increased from mid-2013 forward, the percentage of Level 2 charging events decreased as the Level 1 events increased. This is shown in Figure 36.

Figure 36 - Honda Fit Monthly Charge Type Percentages



To summarize, reviewing the percentage of Honda Fit charges by type and location, the majority of the charging events are occurring at home at Level 2. It is difficult to determine any other trends due to both the increased overall counts over time as well as the increased unknown location counts over time. The data is summarized in Figure 37.

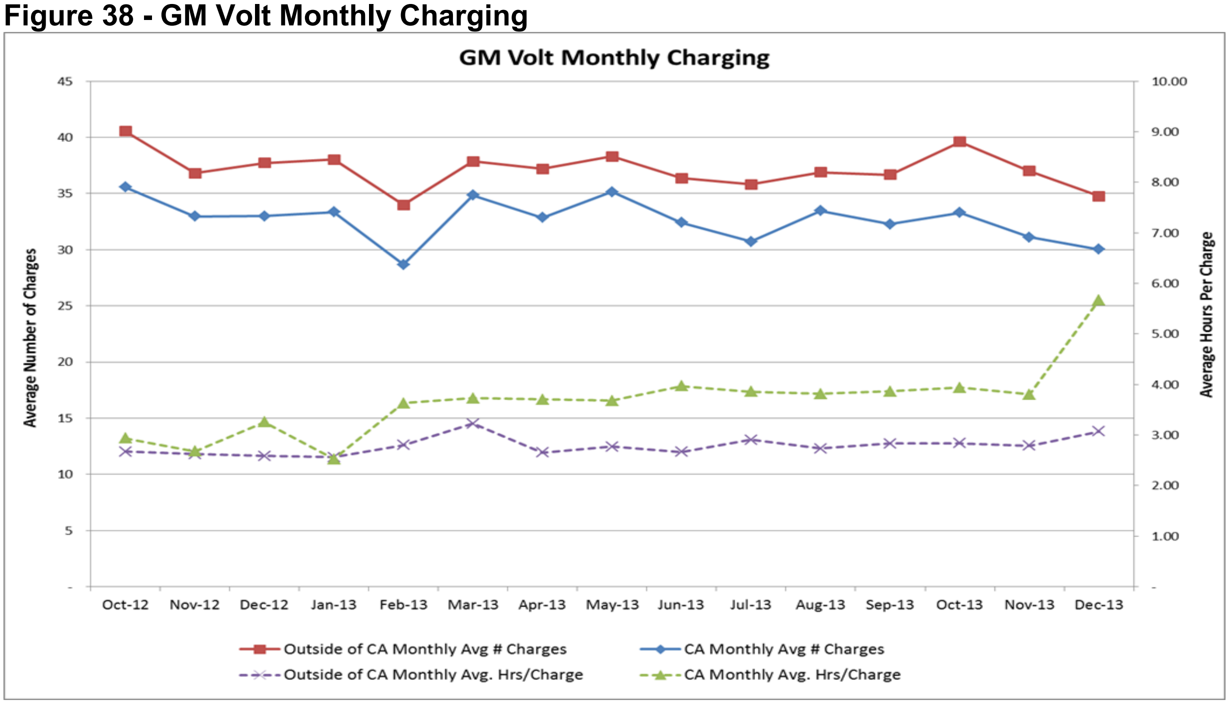
Figure 37 - Honda Fit Monthly Charge Location & Type Percentages



V.B.4. General Motors Plots

Chevrolet Volt did not provide information on the type or location of charges. Therefore; a comparison of the average monthly number of charges, and the average charging time (hours) per charge is shown in the Figure 38. California vehicles show a higher average charge time (hours per charge) with a lower number of charges per month as compared to non-California vehicles.

Figure 38 - GM Volt Monthly Charging



VI. Analysis of activity relevant to understanding criteria pollutant emission benefits

Staff also analyzed the activity data received from manufacturers to better understand the likely impacts on criteria pollutants such as hydrocarbons (HC) and oxides of nitrogen (NOx) from the various PHEVs. In addition to the e-trips and zVMT metrics discussed earlier, staff looked at other factors that could be used to help predict tailpipe emissions from the vehicle. Because tailpipe emissions of criteria pollutants are very dominant at initial engine start and generally much lower and well controlled after the initial engine start, tailpipe emissions can be categorized as start emissions (i.e., emissions associated with the initial engine start event of a trip) and running emissions (i.e., emissions associated with any subsequent engine operation later in the trip). For modern day vehicles, the start emissions represent the vast majority of tailpipe emissions. Accordingly, the analysis of the activity data focused on understanding factors that would influence start emissions.

Start emissions are currently modeled in ARB's EMFAC emission inventory model by looking at the number of engine starts per day as well as the conditions of those starts relevant to predicting the emission rate of the engine start. Because PHEVs can have trips where the engine is not used at all, the in-use data was analyzed to determine not only the total number of vehicle trips per day but specifically the number of trips per day that actually had an ICE start. Table 18 below shows the results of this analysis for the PHEVs. For comparison, the table also includes a value for conventional gasoline cars that was based on the 2012 the California Household Travel Survey (CHTS)[9] results. In general, the table shows that the PHEVs are being used for a similar number of trips per day but only a portion of those are trips where the engine actually is used. For the PHEV with the most electric capability in our study, the GM Volt, the vehicles are averaging only 0.88 trips per day where the engine starts, 22% of all trips taken in the vehicle. For PHEVs with less electric capability, the fraction of trips with an engine start is larger, with engine operation occurring on 86-91% of all trips. The Ford PHEVs were excluded from this analysis because of a data anomaly that prevented accurate logging of all short trips (< 3 kms). Based on the other data sets, the number of such short trips is significant and prevents a valid comparison to the other vehicles.

Table 18 - Approximate Trips per Day

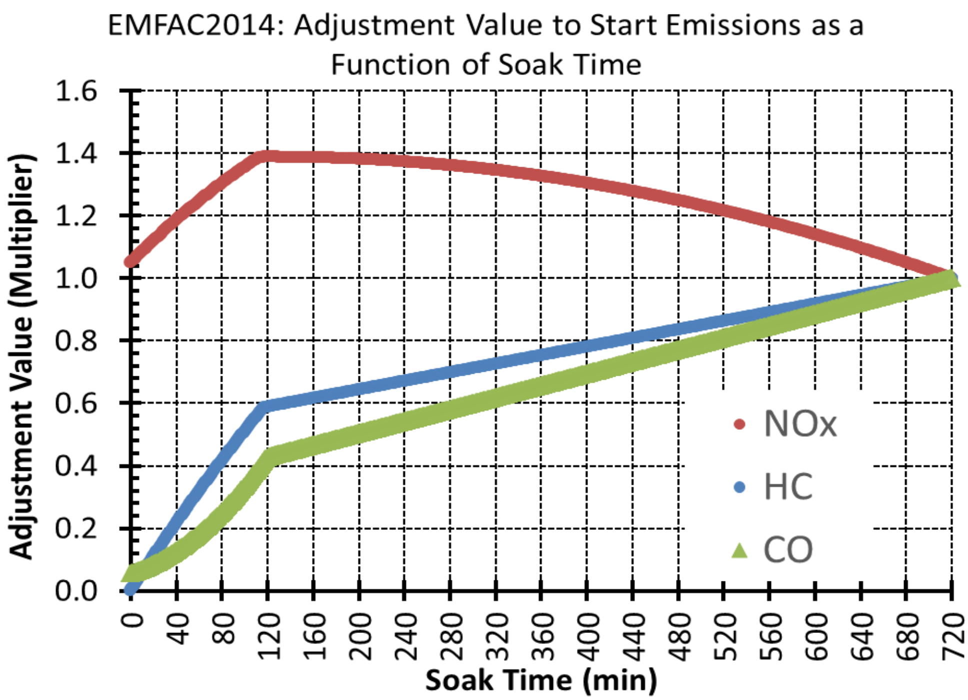
Source of Data	Vehicle - Technology	Total # of All Trips per day	Total # of ICE Trips per day
CHTS 2012	ICE vehicles (Conventional)	4.75	4.75
GM	GM Volt (PHEV)	3.96	0.88
Honda	Honda Accord (PHEV)	4.15	3.80
Toyota	Toyota Prius (PHEV)	4.66	4.02

For light-duty gasoline vehicles, the primary factor influencing the emission rate of the start emissions is the temperature of the catalyst at the time of the start. When the engine is started,

[9] Caltrans 2013. California Department of Transportation. California Household Travel Survey. June 2013 http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_travel_analysis/chts.html

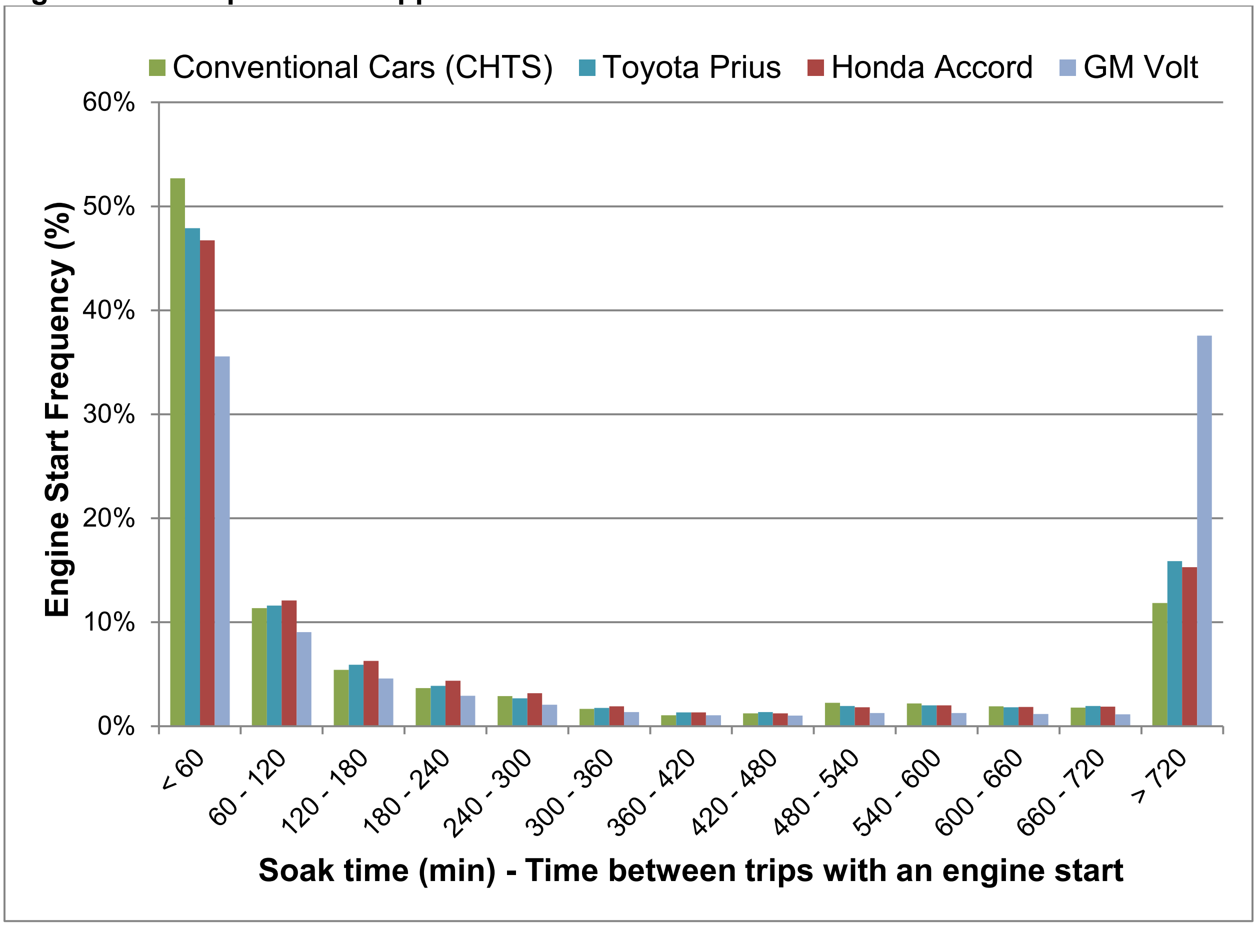
a colder catalyst will require a longer period of time to warm up to the light-off temperature, at which a high conversion efficiency of pollutants is achieved.Generally, a good surrogate for estimating catalyst temperature is the time between vehicle trips ("soak time") because it reflects the period of time the engine is off and the catalyst can cool down to ambient temperature. As shown in Figure 39, the current version of ARB's EMFAC 2014 model uses a multiplicative adjustment factor to adjust the projected emission rate from the start based on the soak time. The data is normalized to the emission rate of an overnight soak, like the official emission test procedures where start emissions are measured, and the emission rate is adjusted on a pollutant specific basis for shorter soak time engine starts. While this figure shows what is used in the current model, it should be noted that ARB is currently working on updates to the EMFAC model including modified adjustment factors based on new test data.

Figure 39 - EMFAC2014 Adjustment Value for Start Emissions



On PHEVs, however, the engine is not utilized on every vehicle trip so the soak time analysis must not look at the soak time from the last trip to the current trip but rather the soak time between the last trip where the engine was operated to the current trip where the engine is operated. Because the provided data could only identify if the engine was operated during a trip but not the exact point within the trip where it did, the analysis could not determine the exact engine off to engine on soak times. But the times between key off and key on trip events for the starts and ends of such trips were available and thus were used to calculate the soak time between trips where the engine was used. Figure 40 below shows the distribution of soak times calculated from the manufacturer data. Again, data for conventional cars from the 2012 CHTS is included for reference and shows that the distribution for the PHEVs is shifted slightly to the right indicating a lower fraction of hot restarts (very short soak times) and a higher fraction of cold starts (longer soak times). The shift is more pronounced on the stronger PHEVs (e.g., GM Volt). Directionally, this makes sense as PHEVs have fewer trips where the engine does start and consequently, longer soak times between the trips where the engine does start. As noted above, the data from the Ford PHEVs was omitted from this analysis given the data logging anomaly.

Figure 40 - Comparison of Approximate Soak Time Distributions in Minutes



To understand the full impact of start emissions, the assumptions in the EMFAC model for PHEVs will need to be updated to include both the new data on starts per day as well as the new distribution of soak time to estimate the emission rates. As a first step, however, staff examined the overnight soaks (720 minutes or longer) to gauge the impact of PHEV behavior on overnight cold start emissions. By combining the results of the average starts per day with the frequency of overnight soaks from the soak time distribution, Table 19 was created. For reference, the conventional vehicles are included which show approximately 12% of trips are overnight cold starts which translates to an average of 0.56 such starts per day. For the GM Volt, while a much higher fraction (38%) of the starts are overnight cold starts, the very low number of trips per day where the engine starts results in an average of only 0.33 overnight cold starts per day. For the Honda and Toyota PHEVs, the slightly higher frequency of overnight soaks combined with only a slightly lower number of starts per day results in an average overnight cold starts per day that is very close to that of conventional cars. However, as these PHEVs do have a lower number of engine starts per day, it is expected that the full modeling will still show some reduction in cumulative engine start emissions relative to conventional vehicles.

Table 19 - Approximate Cold Starts per Day

Source of Data	Vehicle - Technology	Total # of ICE Trips per Day	% of Cold Start Trips (Overnight Soak)	Number of Cold Starts per Day
CHTS 2012	ICE vehicles (Conventional)	4.75	11.86%	0.56
GM	GM Volt (PHEV)	0.88	37.55%	0.33
Honda	Honda Accord (PHEV)	3.80	15.29%	0.58
Toyota	Toyota Prius (PHEV)	4.02	15.88%	0.64

VII. Literature Review

The majority of eVMT research to date has focused on four methodologies: 1) simulations based on non-PEV household travel data, 2) empirical data obtained from short-term loaned PEVs, 3) surveys of PEV owners, and 4) empirical data from actual PEV households. Diverse studies using these four methods agree that eVMT and PHEVs inherent capacity to decrease GHG emissions depend upon driving and charging behavior, driving conditions, the regional energy generation mix, and specific PEV vehicle design. Overall, research is still lacking on how real-world PEV owners use their vehicles in the household context, and analysis of the household eVMT profile.

VII.A. Simulated eVMT based on non-PEV household travel data

The majority of studies simulated PEV performance based on data collected through GPS logging and travel surveys, taken mostly by non-PEV drivers. These studies looked at the theoretical effect that vehicle design, battery capacity, drive patterns, and charging strategies of PEVs would have on petroleum consumption and GHG emissions. Overall, these studies concur that PEVs can have a significant impact on the reduction of petroleum use, but that reduction of GHG emissions is highly dependent on the regional energy generation mix where vehicles are charged.[10,11,12,13,14,15] In addition, driving conditions and driver behavior also impact

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[10] Karabasoglu, 2013, Karabasoglu, O. and J. Michalek, *Influence of driving patterns on life cycle cost and emissions of hybrid and plug-in electric vehicle powertrains.* Energy Policy, 2013. 60: p. 445-461.
[11] Onat, , 2015, Onat, N.C., M. Kucukvar, and O. Tatari, *Conventional, hybrid, plug-in hybrid or electric vehicles? Statebased comparative carbon and energy footprint analysis in the United States.* Applied Energy, 2015. 150: p. 36-49.
[12] Raykin, 2012, Raykin, L., H.L. MacLean, and M.J. Roorda, *Implications of Driving Patterns on Well-to-Wheel Performance of Plug-in Hybrid Electric Vehicles.* Environmental Science & Technology, 2012. 46(11): p. 6363-6370.
[13] Traut, 2012, Traut, E., et al., *Optimal design and allocation of electrified vehicles and dedicated charging infrastructure for minimum life cycle greenhouse gas emissions and cost.* Energy Policy, 2012. 51: p. 524-534.
[14] Tugce, 2016, Tugce, Y., et al., *Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of gasoline and plug-in electric vehicles in the United States.* Environmental Research Letters, 2016. 11(4): p. 044007
[15] Elgowainy 2010, Elgowainy, A., et al., *Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-in Hybrid Electric Vehicles*. 2010, Argonne National Laboratory

GHG benefits, with greatest benefits achieved when usage of CD mode is maximized.[16,17.18 19] Several studies have determined that frequent recharging of PHEVs can reduce PHEV gasoline consumption and decrease operating costs.[20,21,22] A recent modeling study, which used GPS data from travel surveys to calculate second-by-second speed profiles of different trip types, including the effect of ambient temperature, concluded that 87% of vehicles trips driven on a given day across the whole U.S. could be accomplished with the 24-kWh Nissan Leaf based on a single charge per day.[23] This result translates into a potential gasoline reduction of 60.9%. The percent of vehicle driven days that could be replaced with the Leaf was 84-93% across twelve different metropolitan areas, while it was 80.8% for rural areas.

VII.B. Empirical data from PEV loaners

In order to obtain actual on-road data from PHEVs, three early studies funded by Toyota loaned prototype Toyota Prius Plug-in vehicles equipped with on-board data loggers to households for a limited term basis.[24,25,26] As these studies occurred before PHEVs were commercially available, hybrid Toyota Prius vehicles were converted into plug-in versions for each of these studies. A study of 25 households that had access to a prototype Prius Plug-in for 4-6 weeks in northern California found that 20% did not plug-in on a daily basis while 20% plugged-in more than once a day.[27] Although a PHEV with a 5-kWh battery has the potential to reduce petroleum usage by up to 60% below the usage of a comparable HEV, average petroleum displacement in this study was only 14% (Davies, 2013). A study of 125 households that were each loaned one prototype Prius Plug-in for 1 year throughout the U.S. found that 40% of the drivers plugged in the vehicle once a day on days it was driven, but 40% did not plug it in at all[28]. Aggressive opportunistic charging after each trip was estimated to result in approximately

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[16] Kelly, , 2012, Kelly, J.C., J.S. MacDonald, and G.A. Keoleian, *Time-dependent plug-in hybrid electric vehicle charging based on national driving patterns and demographics.* Applied Energy, 2012. 94: p. 395-405.

[17] Raykin, 2012, Raykin, L., M.J. Roorda, and H.L. MacLean, *Impacts of driving patterns on tank-to-wheel energy use of plug-in hybrid electric vehicles.* Transportation Research Part D: Transport and Environment, 2012. 17(3): p. 243-250

[18] Duhon, 2015, Duhon, A., et al., *Chevrolet Volt Electric Utilization.* SAE International Journal of Alternative Powertrains, 2015. 4(2): p. 269-276

[19] Karabasoglu, 2016, Raykin, L, 2012, Traut, E, 2012, Tugce, Y, 2016, Elgowainy, A, 2010).

[20] Björnsson, , 2015, Björnsson, L.-H. and S. Karlsson, *Plug-in hybrid electric vehicles: How individual movement patterns affect battery requirements, the potential to replace conventional fuels, and economic viability.* Applied Energy, 2015. 143: p. 336-347.

[21] Dong, 2012, Dong, J. and Z. Lin, *Within-day recharge of plug-in hybrid electric vehicles: Energy impact of public charging infrastructure.* Transportation Research Part D: Transport and Environment, 2012. 17(5): p. 405-412.

[22] Shiau, 2009, Shiau, C.-S.N., et al., *Impact of battery weight and charging patterns on the economic and environmental benefits of plug-in hybrid vehicles.* Energy Policy, 2009. **37**(7): p. 2653-2663.

[23] Needell, 2016, Needell, Z.A., et al., *Potential for widespread electrification of personal vehicle travel in the United States.* Nature Energy, 2016. 1: p. 16112

[24]Davies, 2013, Davies, J. and K.S. Kurani, *Moving from assumption to observation: Implications for energy and emissions impacts of plug-in hybrid electric vehicles.* Energy Policy, 2013. 62: p. 550-560.

[25] Zoepf, 2013, Zoepf, S., et al., *Charging Choices and Fuel Displacement in a Large-Scale Demonstration of Plug-In Hybrid Electric Vehicles.* Transportation Research Record: Journal of the Transportation Research Board, 2013. 2385: p. 1-10.

[26] Farhar, 2012, Farhar, B.C., D. Maksimovic, and A. Peters. *The Human Dimensions of Plug-in Hybrid Electric Vehicles in Boulder*. 2012 11/28/2012; Available from: https://cleanenergyaction.files.wordpress.com/2012/11/plug-in-hybrid-electric-vehicle-study.pdf.

[27] Davies, 2013.

[28] Zoepf, 2013.

the same fuel savings as increasing the battery size by a factor of five.[25] The third Prius Plug-in prototype study loaned the vehicle for 9-weeks to 142 households in Boulder, Colorado. Of the participating households, only 6% were not satisfied with their PHEV experience, while 76% were dissatisfied with the electric range.[26]

There have been several BEV loaning studies that found drivers with high mileage and those with frequent trips of short distance lifestyles can cover most of their travel needs with a BEV. A study in England of twelve households with access to one of several BEV models, including Nissan Leaf and Peugeot iOn,[29] for six months found that these vehicles were not charged every day.[30] A similar study that gave 75 German households access to BMW ActiveE for three months concluded that even users who have high daily mobility needs can meet their travel needs with a BEV[31]. A study of 72 Irish households with loaned i-MiEV for four months concluded that trips were predominantly frequent in number per day and short in distance[32]. However, it was not clear whether this trend was caused by the new BEV users being anxious about the range of their vehicle or whether it was based on consumer preference.

VII.C. Surveys of PEV households

ARB sponsored surveys of households with new PEVs in California show that although PHEVs with smaller batteries drive more miles, they have less eVMT compared to longer range PHEVs and BEVs as a consequence of battery size, public charging availability, and charging behavior.[33,34] Based on the self-reported driving and charging behavior, the maximum potential eVMT calculated for the Chevrolet Volt and Toyota Plug-in Prius, without workplace charging, was 80% and 26%, while the estimated eVMT was 55 and 16%.[35] PHEVs with smaller batteries tend to charge less often, both overall and at home, compared to longer range PHEVs and BEVs. The percentage of PHEVs that are not charged is inversely proportional to battery range. A total of 14%, 6% and 2% of respective Toyota Plug-in Prius, Ford C-MAX/Fusion Energi, and Chevrolet Volt households self-reported not charging these vehicles in the last 30 days.[36] Interestingly, drivers of PHEVs with smaller batteries were not able to find as many charging opportunities in the same areas compared with higher range PHEV and BEV drivers.[37]

When looking specifically at BEVs driven in California, factors such as body style, self-selection, commute, access to charging infrastructure and sharing of vehicles all seem to play a role in

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[29] The Mitsubishi i-MiEV is sold as the Peugot iOn in Europe

[30] Robinson, 2013, Robinson, A.P., et al., *Analysis of electric vehicle driver recharging demand profiles and subsequent impacts on the carbon content of electric vehicle trips.* Energy Policy, 2013. 61: p. 337-348.

[31] Franke, 2014, Franke, T., et al. *Examining user-range interaction in battery electric vehicles - a field study approach*. in *5th International Conference on Appliced Human Factors and Ergonomics*. 2014. Kraków, Poland.

[32] Weldon, 2016, Weldon, P., et al., *An investigation into usage patterns of electric vehicles in Ireland.* Transportation Research Part D: Transport and Environment, 2016. 43: p. 207-225.

[33] Tal, 2014, Tal, G., et al., *Charging Behavior Impacts on Electric Vehicle Miles Traveled: Who Is Not Plugging In?* Transportation Research Record: Journal of the Transportation Research Board, 2014(2454): p. 53-60.

[34] Nicholas, 2016a. Nicholas, M.A. and G. Tal, *EVMT in the Household Fleet: Integrating Battery Electric Vehicles into Household Travel*, in *Transportation Research Board*. 2016: Washington D.C. p. 16-6994. https://trid.trb.org/view.aspx?id=1394567

[35] Tal, 2014.

[36] Nicholas, 2016a.

[37] Tal, 2014.

determining eVMT, in addition to electric range.[38] Range alone does not explain reported eVMT. For example, the self-reported annual eVMT of the Fiat 500e (7,912 miles) is much lower than expected given its all electric range of 87 miles compared with other BEVs of similar range such as the Honda Fit EV and the Chevrolet Spark EV (11,049 and 9,167 miles). Although the Tesla Model S and Toyota RAV4 EV have very different electric ranges greater than 100 miles (265 vs 113 miles), both vehicles get fairly similar annual eVMT (12,174 vs 11,519 miles) (Nicholas, 2016). The Honda Fit EV had the highest annual eVMT (11,049 miles) of the BEVs with an electric range below 100 miles, followed by Nissan Leaf (9,511 miles), Ford Focus Electric (9,442 miles), Chevrolet Spark EV (9,167 miles), BMW i3 (8,169 miles), Fiat 500e (7,912 miles) and lastly, the Smart Fortwo (6,690 miles). Additionally, the overall share of household eVMT is not dictated by vehicle range alone. For example, the Fiat 500e and the Toyota RAV4 EV contributed to the smallest and largest share of household eVMT (~37-49%).

A separate ARB sponsored survey of used PEV owners estimated the total annual miles driven by used PEV owners based on self-reported odometer readings at the time of survey completion and time of purchase.[39] Comparing these results with those from a survey of new PEV owners reveals that used PHEVs tend to be driven more than new PHEVs. For example, the used Ford Fusion Energi and Chevrolet Volt were driven 15,692 and 12,000 median annual miles while the new versions were driven 12,600 and 10,800 median annual miles. Furthermore, respondents with smaller battery PHEV models were more likely to use their PEV as a conventional hybrid vehicle. For example, 30% of used Prius Plug-in owners reported they plugged in their vehicle four times or less in the last 30 days. In contrast, less than 15% of new Prius Plug-in owners reported plugging in their vehicle four times or less in the last 30 days. Thus, as used PHEVs with smaller batteries are driven more and are plugged in less than similar new PHEVs, the percent eVMT they are able to achieve must be decreasing compared to new PHEVs. The usage trends for used BEVs are mixed depending on their battery size. While the used Tesla Model S was driven more than the new Tesla Model S (12,798 versus 11,200 median annual miles), used BEVs with smaller electric range were driven less than the new version of the same BEVs. For instance, the used and new Nissan Leaf vehicles were driven 7,836 and 9,400 annual median miles.

A recent Norwegian survey of PEV consumers determined that BEV owners utilized their vehicles more for all types of trips, but less on vacation than PHEV and ICE households.[40] In contrast to results from California PEV owner surveys, the BEV drivers have a longer work commute than PHEV or ICE owners in Norway. This could be a result of the different set of tax policies and incentives between the two regions. Different BEV models have different eVMT profiles in Norway too. The Tesla Model S was driven the most per year on average (14,520 miles) followed by the Kia Soul EV (10,986 miles), Volkswagen E-Golf (10,372 miles), Nissan Leaf (9,849 miles), BMW i3 (9,505 miles), and the Renault Zoe (9,300 miles). In general,

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[38] Nicholas, 2016a.
[39] Tal, 2016, Tal, G. and M.A. Nicholas, *First Look at the Plug-in Vehicles Secondary Market - Draft Working Paper*. 2016, Instiute of Transportation Studies, University of California Davis.
[40] Figenbaum, 2016, Figenbaum, E. and M. Kolbenstvedt, *Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle Users: results from a survey of vehicle owners.* 2016, Institute of Transport Economics, Norwegian Centre for Transport Research: Oslo.

Norwegian PHEV owners self-reported to have driven 55% of the time in all electric drive mode ranging from 38% for the Prius Plug-in to 83% for the Opel Ampera.[41]

ARB sponsored surveys of households with new PEVs in California show that, although PHEVs with smaller batteries drive more miles, they have less eVMT compared to longer range PHEVs and BEVs as a consequence of battery size, public charging availability, and charging behavior.[42,43] Based on the self-reported driving and charging behavior, the maximum potential eVMT calculated for the Chevrolet Volt and Toyota Plug-in Prius, without workplace charging, was 80% and 26%, while the estimated eVMT was 55 and 16%[44]. PHEVs with smaller batteries tend to be charged less often, both overall and at home, compared to longer range PHEVs and BEVs.[45] The motivation to plug in a PHEV was found to be a function of electric range recovered during the charge event and accordingly, PHEVs with longer range are more likely to be plugged in when empty versus smaller range PHEVs at a similar level of depleted charge. The percentage of PHEVs that are not charged is inversely proportional to battery range, and this percentage has roughly doubled for new PEV drivers between 2015 and 2016 as gasoline prices have decreased.[46] Interestingly, drivers of PHEVs with smaller batteries were not able to find as many charging opportunities in the same areas compared with higher range PHEV and BEV drivers.[47]

When looking specifically at BEVs driven in California, factors such as body style, self-selection, commute, access to charging infrastructure and sharing of vehicles all seem to play a role in determining eVMT, in addition to electric range.[48] Range alone does not explain reported eVMT. For example, the self-reported annual eVMT of the Fiat 500e (7,912 miles) is much lower than expected given its all electric range of 87 miles compared with other BEVs of similar range such as the Honda Fit EV and the Chevrolet Spark EV (11,049 and 9,167 miles). Although the Tesla Model S and Toyota RAV4 EV have very different electric ranges greater than 100 miles (265 vs 113 miles), both vehicles get fairly similar annual eVMT (12,174 vs 11,519 miles) (Nicholas, 2016). The Honda Fit EV had the highest annual eVMT (11,049 miles) of the BEVs with an electric range below 100 miles, followed by Nissan Leaf (9,511 miles), Ford Focus Electric (9,442 miles), Chevrolet Spark EV (9,167 miles), BMW i3 (8,169 miles), Fiat 500e (7,912 miles) and lastly, the Smart Fortwo (6,690 miles). Additionally, the overall share of household eVMT is not dictated by vehicle range alone. For example, the Fiat 500e and the Toyota RAV4 EV contributed to the smallest and largest share of household eVMT (~37-49%).

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[41] Figenbaum, 2016.
[42] Tal, 2014
[43] Nicholas, 2016a, Nicholas, M.A. and G. Tal, *EVMT in the Household Fleet: Integrating Battery Electric Vehicles into Household Travel*, in *Transportation Research Board*. 2016: Washington D.C. p. 16-6994. https://trid.trb.org/view.aspx?id=1394567
[44] Tal, 2014.
[45] Nicholas, 2016b, Nicholas, M., G. Tal, and T. Turrentine, Advanced Plug in Electric Vehicle Travel and Charging Behavior Interim Report. 2016, Plug-in Hybrid & Electric Vehicle Research Center, University of California Davis, Research Report UCD-ITS-RR-16-10. https://itspubs.ucdavis.edu/index.php/research/publications/publication-detail/?pub_id=2692.
[46] Nicholas, 2016b
[47] Tal, 2014.
[48] Nicholas, 2016a.

A separate ARB sponsored survey of used PEV owners estimated the total annual miles driven by used PEV owners based on self-reported odometer readings at the time of survey completion and time of purchase.[49] Comparing these results with those from a survey of new PEV owners reveals that used PHEVs tend to be driven more than new PHEVs. For example, the used Ford Fusion Energi and Chevrolet Volt were driven 15,692 and 12,000 median annual miles while the new versions were driven 12,600 and 10,800 median annual miles. Furthermore, respondents with smaller battery PHEV models were more likely to use their PEV as a conventional hybrid vehicle. For example, 30% of used Prius Plug-in owners reported they plugged in their vehicle four times or less in the last 30 days. In contrast, less than 15% of new Prius Plug-in owners reported plugging in their vehicle four times or less in the last 30 days. Thus, as used PHEVs with smaller batteries are driven more and are plugged in less than similar new PHEVs, the percent eVMT they are able to achieve must be decreasing compared to new PHEVs. The usage trends for used BEVs are mixed depending on their battery size. While the used Tesla Model S was driven more than the new Tesla Model S (12,798 versus 11,200 median annual miles), used BEVs with smaller electric range were driven less than the new version of the same BEVs. For instance, the used and new Nissan Leaf vehicles were driven 7,836 and 9,400 annual median miles.

A recent Norwegian survey of PEV consumers determined that BEV owners utilized their vehicles more for all types of trips, but less on vacation than PHEV and ICE households.[50] In contrast to results from California PEV owner surveys, the BEV drivers have a longer work commute than PHEV or ICE owners in Norway. This could be a result of the different set of tax policies and incentives between the two regions. Different BEV models have different eVMT profiles in Norway too. The Tesla Model S was driven the most per year on average (14,520 miles) followed by the Kia Soul EV (10,986 miles), Volkswagen E-Golf (10,372 miles), Nissan Leaf (9,849 miles), BMW i3 (9,505 miles), and the Renault Zoe (9,300 miles). In general, Norwegian PHEV owners self-reported to have driven 55% of the time in all electric drive mode ranging from 38% for the Prius Plug-in to 83% for the Opel Ampera.[51]

VII.D. Empirical data from PEV households and fleets

Perhaps the most accurate method to study eVMT is to obtain high-resolution driving and charging data during a long period of time (>1 year) directly from real-world PEV households. One pioneering study that utilized vehicle telematics to do this was the “EV Project” from the INL funded by the US DOE. The driving and charging profiles of 1,867 Chevrolet Volt and 4,038 Nissan Leaf vehicles were studied between 2012-2013 in 22 metropolitan areas across the United States, including San Diego, Los Angeles, and San Francisco.[52] Parameters recorded for this study by the Volt and Leaf telematics systems include key-on and key-off events, odometer, EV-mode odometer, number of trips, gasoline fuel economy, battery state of charge

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[49] Tal, 2016, Tal, G. and M.A. Nicholas, *First Look at the Plug-in Vehicles Secondary Market - Draft Working Paper*. 2016, Institute of Transportation Studies, University of California Davis. UCD-ITS-WP-16-02

[50] Figenbaum, 2016, Figenbaum, E. and M. Kolbenstvedt, *Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle Users: results from a survey of vehicle owners.* 2016, Institute of Transport Economics, Norwegian Centre for Transport Research: Oslo.

[51] Figenbaum, 2016.

[52] Francfort, 2015, Francfort, J., et al., *Plug-in Electric Vehicle and Infrastructure Analysis.* 2015, Idaho National Laboratory: Idaho.

(SOC), and the number, type and location of charging events. Participants of the "EV Project" that lived in 13 cities received a free level 2 EVSE for their home and up to $1,200 to cover installation expenses.

As illustrated in Table 20, Volt vehicles accumulated more annual VMT with an average of 12,238 miles while the Leaf vehicles only achieved 10,352 miles. Despite having a smaller electric range, Volt drivers averaged only 6% fewer annual eVMT than the Leaf drivers. On average, Volt drivers charged more often (1.5 charges per day on days driven) and tended to deplete their batteries prior to recharging compared with Leaf drivers (1.1 charges per day on days driven) who tended to recharge with significant range left in their batteries. The "EV Project" participants that had access to workplace charging had higher annual VMT than overall project participants; Volt and Leaf drivers with access to workplace charging accumulated an average of 13,759 and 11,882 miles per year. A separate analysis by INL based on these "EV Project" Leaf vehicles with workplace charging concluded that workplace charging can serve as a virtual range extender.[53] At least 14% of Leaf vehicles needed workplace charging to complete their daily commutes most of the time, while 42% of vehicles needed it at least 5% of commuting days. On days when these drivers charged at work, they drove an additional 15% more miles than when they did not charge at work. The top 100 mileage Leaf and Volt vehicles participating in the "EV Project" had an average annual VMT of 19,048 and 25,088 miles respectively.[54] Although these high mileage PEVs were charged away from home more often, at least two thirds of the charging was still done at home. The high mileage Leaf and Volt vehicles in the "EV Project" were charged away from home 34% and 21% of the time compared to just 20-22% and 14-17% for all Leaf and Volt vehicles.[55] It is unclear whether the high mileage Volt vehicles in this study had a different eVMT profile.

INL also analyzed the travel data supplied by different car manufacturers for a variety of other PEVs, as shown in Table 20.[56] Smaller range PHEVs tend to be driven longer distances than larger battery PHEVs and BEVs. There was a wide range of average percent eVMT for different PHEVs increasing with electric range, spanning from 16% for the Toyota Prius Plug-in to 75% for the Volt. One of the strengths of the "EV Project" is the large sample size. However, there may be biases present in the data because the telematics systems used to obtain the data were only available for the higher trim of some of these vehicle models, such as the Prius Plug-in.

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[53] INL, 2014, INL, *The EV Project: Charging and Driving Behavior of Nissan Leaf Drivers in The EV Project with Access to Workplace Charging*. 2014, Idaho National Laboratory: Idaho.

[54] INL, 2015, INL, *The EV Projec: What Were the Driving and Charging Behaviors of High Mileage Accumulators?* 2015, Idaho National Laboratory.

[55] INL, 2015.

[56] Carlson, 2015, Carlson, B. *Electric Vehicle Mile Traveled (eVMT): on-road results and analysis*. DOE Vehicle Technologies Program Annual Merit Review 2015; Available from: http://energy.gov/sites/prod/files/2015/07/f24/vss171_carlson_2015_p.pdf.

Table 20 - Annualized statistics of PEVs from INL[57,58] and UCD[59] studies

PEV	Study	Mean Annual VMT	Mean Annual eVMT	% Annual eVMT by PEV	Annual Average HH VMT	% Annual eVMT by Household	% Trips without ICE Starting	Sample Size
Toyota Prius Plug-in	INL	15,136	2,484	16.4%	NA	NA	NA	1,523
	UCD	12,268	2,829	23.1%	19,112	14.8	21.9	18
Ford C-MAX Energi	INL	12,403	4,069	32.8%	NA	NA	NA	5,368
Ford Fusion Energi	INL	12,403	4,337	35.0%	NA	NA	NA	5,803
Ford C-MAX & Fusion Energi	UCD	11,778	4,982	42.3%	20,289	24.6	56.2	18
Chevrolet Volt	INL	12,238	9,112	74.5%	NA	NA	NA	1,867
	UCD	11,122	8,186	73.6%	18,316	44.7	87.2	18
	GM	NA	NA	74%	NA	NA	NA	>48,000
Nissan Leaf	INL	9,697	9,697	100.0%	NA	NA	NA	4,038
	UCD	10,230	10,230	100.0%	23,575	43.4	NA	18
Ford Focus Electric	INL	9,548	9,548	100.0%	NA	NA	NA	2,196
Honda Fit EV	INL	9,680	9,680	100.0%	NA	NA	NA	645
Honda Accord Plug-in	INL	14,986	3,336	22.3%	NA	NA	NA	189

An analysis by General Motors (GM) of more than 48,000 Volt vehicles with active OnStar accounts between October 2013 and September 2014 in the U.S. and Canada concluded that 74% of the miles driven on these vehicles were eVMT.[60] Similar driving and charging parameters were analyzed as in the "EV Project." A 70% reduction in cold starts compared to conventional gasoline vehicles under the same driving conditions was quantified. Finally, this study estimated that the second generation Volt will achieve 80% eVMT assuming the same driving and charging patterns.

ARB and the California Energy Commission are sponsoring a project at the University of California Davis (UCD) to study consumers' actual usage of PEVs in California. The goal of this project is to quantify eVMT within the household context among a variety of different electric range PHEVs (Toyota Plug-in Prius, Chevrolet Volt, and the Ford Fusion/C-MAX Energi), BEVs (Nissan Leaf and Tesla Model S), and BEVs with a range extending internal combustion engine

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[57] Francfort,2015,
[58] Carlson, 2015.
[59] Nicholas, 2016b
[60] Duhon, 2015.

(BEVx) (BMW i3 REX). This study is collecting detailed driving and charging data utilizing a specialized data-logger that records key-on and key-off events, odometer, speed, acceleration, state of charge, location of vehicle, and charging event (location, duration, level). This study completed the first year of logged data on all the vehicles from 18 Plug-in Prius, 18 Fusion/C-MAX Energi, 18 Chevrolet Volt, and 18 Leaf households.[61]

As presented at the September 2016 Advanced Clean Car Symposium,[62] the average annual VMT of participants in the UCD study is fairly similar to the INL study (Table 20), except for the Prius Plug-in which was about 3,000 miles less in the UCD study. The percent annual eVMT by PEV was roughly similar for the Volt but higher for the Prius Plug-in and Energi models in the UCD study relative to the INL study, in part because vehicles that did not plug in were excluded from the UCD study. Differences in the results of the two studies could be due to the sampling selection, size, location, available infrastructure, or other biases inherent in these studies. The timing of each study could also affect the results, with the UCD study collecting data more recently (2015-2016) over the data used in the INL study (2012-2013). One of the strengths of the UCD study is that it is quantifying the percent eVMT per household based on total VMT across all vehicles. The percent eVMT per household is lowest for the smaller battery PHEVs as the vehicles are used more for overall driving in the household despite not having enough electric range in the PHEV to meet the driving needs. In the household study, the choice of vehicle in the context of ICE usage is also explored. The study does find that the electric range of both the Chevrolet Volt and Nissan Leaf are maximized so that the vehicles are more likely to be used instead of the ICE on days where all driving can be accomplished on one charge, but less so for the Plug-in Prius, Ford Fusion Energi and Ford C-Max Energi. It is unclear the degree to which this maximization of use within electric range is due to customers matching the vehicle purchase to driving patterns or whether the vehicle architecture encourages maximization of electric range post-purchase.

While the Nissan Leaf households have the largest average eVMT, they also have the largest household VMT and therefore, not the highest percent eVMT by household. In the UCD study, Nissan Leaf households also had more vehicles and drivers per household than the other PEVs, resulting in higher household miles in ICEs and a lower percent eVMT for the household. The overall household VMT is smallest for the Chevrolet Volt households, so they have the highest percent eVMT by household.

The percent of trips without an ICE starting were also quantified.[63] The Volt achieved 87% of its trips without the gasoline engine, whereas only 22% of the trips in the Prius Plug-in did not use the ICE. Furthermore, over one-sixth of the Prius Plug-in, one-twentieth of the C-MAX Energi, and one-thirteenth of the Fusion Energi engine starts were determined to have been high-power

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[61] Nicholas, 2016b

[62] Nicholas, 2016c. Michael Nicholas, Gil Tal. University of California Davis, Plug-in Hybrid and Electric vehicle research Center. Advanced Clean Car 2016 Symposium Presentation "Advanced Plug-in Electric Vehicle Driving and Charging Behavior" September 2016. https://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/pev_data_from_uc_davis_household_study_first_year_michael_nicholas.pdf

[63] Nicholas, 2016c.

cold starts, which tend to emit more criteria pollutants than a normal cold start thus potentially mitigating some of the environmental benefits of PHEVs.

The UCD project is continuing with data collection, including all the models listed above. The next two 1-year phases of the study began in the early and late fall of 2016, respectively, and a final phase of data collection will begin in fall 2017. Because this project is providing unique data that will be used to inform future policies, ARB is sponsoring a similar project focused on the household-level driving and fueling of emerging technology zero-emission vehicles including Toyota Prius Prime, Chrysler Pacifica, Chevrolet Bolt and Toyota Mirai. This new project will commence in early 2017.

VIII. Summary

This Appendix G describes staff analysis of the in-use trip level vehicle data collected from various plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV), and range extended BEVs (BEVx). In-use trip and charge data, including more than 500,000 individual records for more than 94,000 vehicles from seven major OEMs (BMW, Ford, GM, Honda, Nissan, Tesla, and Toyota), were analyzed to assess the relative performance of the BEVs and PHEVs. The analysis found that the lower range (75-100 mile) BEVs are, on average, being driven less each year than longer range (Tesla) BEVs or PHEVs. When looking at eVMT, the analysis confirmed the longer range/higher electric only capability PHEVs resulted in a higher fraction of electric miles than shorter range PHEV. However, even the strongest PHEV (GM Volt) achieves only about 75% of the electric miles that a typical lower range BEV like the Nissan Leaf travels in a year. Data shows that newer model year BEVs and PHEVs are being driven more than earlier model years but it varies among PHEV models as to whether the percentage of eVMT is staying constant or dropping in conjunction with the increase in total miles. The impact of leasing terms (mileage caps) appears to have a large influence on annual VMT as Nissan Leafs with 15,000 mi/year lease terms averaged significantly higher VMT than those with 12,000 mi/year lease terms. There is substantial variability within each PHEV vehicle model as to how individual vehicles are being used and some weak correlations are observed where, as average daily VMT increase, the relative eVMT percentage tends to decrease while the eVMT absolute miles increases. Slightly stronger correlations are observed with average number of charge events per day where an increase in charge events per day consistently shows overall increases in both percent and absolute eVMT.

Regarding charging, the Nissan Leaf was studied and the data shows that newer model year Leaf owners are generally using less Level 2 charging and more Level 1 charging. Usage of DC fast charging is also showing a slight increase and increased usage appears to correlate to higher annual VMT.

The activity data was also studied to better understand criteria pollutant (primarily HC and NOx) impacts of the PHEVs. The zVMT metric showed similar, but more pronounced, trends than eVMT with the shorter range and lower all electric capability PHEVs having a very small portion of their total VMT from "BEV-like" trips where no criteria pollutants were emitted. PHEVs do show some reduction in engine starts per day with the GM Volt showing the largest reduction with only ~20% of the number of starts per day as a conventional car. PHEVs do, however, average longer time periods of engine off time between trips such that a larger share of the engine starts are cold starts, where emissions are the highest. Cumulatively, start emissions are likely reduced by having fewer starts per day but the higher fraction of cold starts offsets part of this reduction.

Several studies have been conducted to understand how BEVs and PHEVs are being used and while the same general trends are observed, calculated metrics or averages continue to shift based on the actual data sample studied. The differences observed in where vehicles are used, age and model year of the vehicles, and the driving needs and charging behavior of the individual owner can have a significant impact.

IX. References

Björnsson, 2015, Björnsson, L.-H. and S. Karlsson, *Plug-in hybrid electric vehicles: How individual movement patterns affect battery requirements, the potential to replace conventional fuels, and economic viability.* Applied Energy, 2015. 143: p. 336-347.

Caltrans 2013. California Department of Transportation. California Household Travel Survey. June 2013 http://www.dot.ca.gov/hq/tpp/offices/omsp/statewide_travel_analysis/chts.html

Carlson, 2015, Carlson, B. *Electric Vehicle Mile Traveled (eVMT): on-road results and analysis*. DOE Vehicle Technologies Program Annual Merit Review 2015; Available from: http://energy.gov/sites/prod/files/2015/07/f24/vss171_carlson_2015_p.pdf.

Davies, 2013, Davies, J. and K.S. Kurani, *Moving from assumption to observation: Implications for energy and emissions impacts of plug-in hybrid electric vehicles.* Energy Policy, 2013. 62: p. 550-560.

Dong, 2012, Dong, J. and Z. Lin, *Within-day recharge of plug-in hybrid electric vehicles: Energy impact of public charging infrastructure.* Transportation Research Part D: Transport and Environment, 2012. 17(5): p. 405-412.

Duhon, 2015, Duhon, A., et al., *Chevrolet Volt Electric Utilization.* SAE International Journal of Alternative Powertrains, 2015. 4(2): p. 269-276.

Elgowainy, 2010, Elgowainy, A., et al., *Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-in Hybrid Electric Vehicles*. 2010, Argonne National Laboratory.

Farhar, 2012, Farhar, B.C., D. Maksimovic, and A. Peters. *The Human Dimensions of Plug-in Hybrid Electric Vehicles in Boulder*. 2012 11/28/2012; Available from: https://cleanenergyaction.files.wordpress.com/2012/11/plug-in-hybrid-electric-vehicle-study.pdf

Figenbaum, 2016, Figenbaum, E. and M. Kolbenstvedt, *Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle Users: results from a survey of vehicle owners*. 2016, Institute of Transport Economics, Norwegian Centre for Transport Research: Oslo

Francfort, 2015, Francfort, J., et al., *Plug-in Electric Vehicle and Infrastructure Analysis*. 2015, Idaho National Laboratory: Idaho.

Franke, 2014, Franke, T., et al. *Examining user-range interaction in battery electric vehicles - field study approach*. in *5th International Conference on Appliced Human Factors and Ergonomics*. 2014. Kraków, Poland.

INL, 2014, INL, *The EV Project: Charging and Driving Behavior of Nissan Leaf Drivers in The EV Project with Access to Workplace Charging*. 2014, Idaho National Laboratory: Idaho.

INL, 2015, INL, *The EV Projec: What Were the Driving and Charging Behaviors of High Mileage Accumulators?* 2015, Idaho National Laboratory

Karabasoglu, 2013, Karabasoglu, O. and J. Michalek, *Influence of driving patterns on life cycle cost and emissions of hybrid and plug-in electric vehicle powertrains.* Energy Policy, 2013. 60: p. 445-461.

Kelly, 2012, Kelly, J.C., J.S. MacDonald, and G.A. Keoleian, *Time-dependent plug-in hybrid electric vehicle charging based on national driving patterns and demographics.* Applied Energy, 2012. 94: p. 395-405.

Nicholas, 2016a, Nicholas, M.A. and G. Tal, *EVMT in the Household Fleet: Integrating Battery Electric Vehicles into Household Travel*, in *Transportation Research Board*. 2016: Washington D.C. p. 16-6994.

Nicholas, 2016b, Nicholas, M., G. Tal, and T. Turrentine, *Advanced Plug in Electric Vehicle Travel and Charging Behavior Interim Report*. 2016, Plug-in Hybrid & Electric Vehicle Research Center, University of California Davis, Research Report, UCD-ITS-RR-16-10. https://itspubs.ucdavis.edu/index.php/research/publications/publication-detail/?pub_id=2692

Nicholas, 2016c. Michael Nicholas, Gil Tal. University of California Davis, Plug-in Hybrid and Electric vehicle research Center. Advanced Clean Car 2016 Symposium Presentation "Advanced Plug-in Electric Vehicle Driving and Charging Behavior" September 27, 2016. https://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/pev_data_from_uc_davis_household_study_first_year_michael_nicholas.pdf

Needell, 2016, Needell, Z.A., et al., *Potential for widespread electrification of personal vehicle travel in the United States.* Nature Energy, 2016. 1: p. 16112.

Onat, 2015, Onat, N.C., M. Kucukvar, and O. Tatari, *Conventional, hybrid, plug-in hybrid or electric vehicles? State-based comparative carbon and energy footprint analysis in the United States.* Applied Energy, 2015. 150: p. 36-49.

Raykin, 2012, Raykin, L., H.L. MacLean, and M.J. Roorda, *Implications of Driving Patterns on Well-to-Wheel Performance of Plug-in Hybrid Electric Vehicles.* Environmental Science & Technology, 2012. 46(11): p. 6363-6370.

Raykin, 2012, Raykin, L., M.J. Roorda, and H.L. MacLean, *Impacts of driving patterns on tank-to-wheel energy use of plug-in hybrid electric vehicles.* Transportation Research Part D: Transport and Environment, 2012. 17(3): p. 243-250.

Robinson, 2013 Robinson, A.P., et al., *Analysis of electric vehicle driver recharging demand profiles and subsequent impacts on the carbon content of electric vehicle trips.* Energy Policy, 2013. 61: p. 337-348.

Shiau, 2009, Shiau, C.-S.N., et al., *Impact of battery weight and charging patterns on the economic and environmental benefits of plug-in hybrid vehicles.* Energy Policy, 2009. 37(7): p. 2653-2663

Tal, 2014, Tal, G., et al., *Charging Behavior Impacts on Electric Vehicle Miles Traveled: Who Is Not Plugging In?* Transportation Research Record: Journal of the Transportation Research Board, 2014(2454): p. 53-60.

Tal, 2016, Tal, G. and M.A. Nicholas, *First Look at the Plug-in Vehicles Secondary Market - Draft Working Paper*. 2016, Instiute of Transportation Studies, University of California Davis. UCD-ITS-WP-16-02. https://itspubs.ucdavis.edu/index.php/research/publications/publication-detail/?pub_id=2693

Traut, 2012, Traut, E., et al., *Optimal design and allocation of electrified vehicles and dedicated charging infrastructure for minimum life cycle greenhouse gas emissions and cost.* Energy Policy, 2012. 51: p. 524-534.

Tugce, 2016, Tugce, Y., et al., *Effect of regional grid mix, driving patterns and climate on the comparative carbon footprint of gasoline and plug-in electric vehicles in the United States.* Environmental Research Letters, 2016. 11(4): p. 044007.

Weldon, 2016, Weldon, P., et al., *An investigation into usage patterns of electric vehicles in Ireland.* Transportation Research Part D: Transport and Environment, 2016. 43: p. 207-225.

Zoepf , 2013, Zoepf, S., et al., *Charging Choices and Fuel Displacement in a Large-Scale Demonstration of Plug-In Hybrid Electric Vehicles.* Transportation Research Record: Journal of the Transportation Research Board, 2013. 2385: p. 1-10.