

Chevrolet Volt Electric Utilization

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ABSTRACT

Evaluation of one year of in-use operating data from first generation Chevrolet Volt Extended-Range Electric Vehicle (E-REV) retail customers determined trip initial Internal Combustion Engine (ICE) starts were reduced by 70% relative to conventional vehicles under the same driving conditions. These Volt drivers were able to travel 74% of their total miles in EV without requiring the ICE's support. Using this first generation Volt data, performance of the second generation Volt is projected. The Southern California Association of Governments (SCAG) Regional Travel Survey (RTS) data set was also processed to make comparisons between realistic PHEV constraints and E-REV configurations. A Volt characteristic E-REV was found to provide up to 40 times more all-electric trips than a PHEV over the same data set.

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INTRODUCTION

Electrified vehicles are a fast growing and very relevant component of the automotive marketplace. Worldwide vehicle sales are projected to be on pace for significant growth for the remainder of this decade and several decades to come [1,2]. In addition, the global car parc, a measure of the number of vehicles in use, is on pace to grow from about one billion vehicles today to approximately 2.0 billion vehicle in 2035 [3]. With these trends, the energy consumption and emissions implications of these vehicles is greatly important to future economic and environmental situations. Both of these items can be improved by effectively using electricity as a mobile energy source on a portion of these vehicles.

Many analysts agree that electrified vehicle growth is expected to outpace the growth of car sales by a significant amount [3,4]. From a societal perspective, electrified vehicles that use grid energy instead of petroleum are desirable because they diversify the primary energy sources used for transportation. This has positive implications on energy security for nations, CO₂ generation (depending on fuel used to generate electricity), and more centralized treatment of other criteria emissions.¹ Additionally, electrified vehicles are seen by consumers as having highly desirable attributes, like operating cost, but report that usefulness and acquisition costs limit attractiveness [5].

Ultimately, the effectiveness of electrification depends on the pace of adoption, which will hinge on development and deployment of technologies that simultaneously improve the customer utility of the vehicles and the costs to acquire and operate them. Many automotive OEMs and the extended supply bases are engaged to tackle this challenge. To date, there are a variety of electrified vehicle types that

have been studied, developed, produced, and sold. In this paper we focus on two types, the Plug-in Hybrid Electric Vehicle (PHEV) and the Extended-Range Electric Vehicle (E-REV).

A PHEV has been defined by the SAE [6] as "A hybrid vehicle with the ability to store and use off-board electrical energy in the RESS (rechargeable energy storage system)." An E-REV has been defined [7] as "A vehicle that functions as full-performance battery electric vehicle when energy is available from an onboard RESS and having an auxiliary energy supply that is only engaged when the RESS energy is not available". In that prior publication, PHEVs and EREVs were largely conceptual and projections were made comparing their respective attributes, especially energy consumption and emissions [7]. These were based purely upon simulation of prototypical vehicle attributes projected over some aggregate commute driving schedules.

At this point in time, sufficient production examples and quantities of both PHEVs and E-REVs have been sold such that a real world assessment of their effectiveness at driving electrically can now be compared to prior predictions. The Chevrolet Volt has been produced since 2010 and is largely the prototypical E-REV that was examined in the 2008 paper [7]. There are a few competitor PHEVs that have subsequently been put into production in 2011, 2012, and 2014. They vary in capability but are representative of PHEVs having attributes previously described as "conversion PHEVs" or "urban capable" PHEVs. This paper will compare them in their ability to increase all-electric driving, reduce petroleum consumption, and eliminate initial engine starts (i.e. "cold starts") and associated criteria emissions. Lastly, it will explore the avenues for improvement in E-REVs beyond the current Chevrolet Volt and discuss the relative benefits of improved electric range and extended range driving efficiency on the energy consumption and emissions in the real world.

1. In this paper the term criteria emissions is used to refer to CO, NO_x, HC, and Particulate Matter.

DATA OVERVIEW

Chevrolet Volt in-use operating data was collected from all MY11-MY14 retail vehicles sold in the United States and Canada with active OnStar accounts. The data was collected via OnStar over a one-year period from October 2013 through September 2014, ensuring that all four seasons were represented. A total of 667 million miles of total customer driving was processed and analyzed across a total vehicle count that ranged from 48,573 to 63,057 over the 1-year period. The data was collected with the permission of the vehicle customers, in accordance with their OnStar agreements which allow their driving data to be used for research and development purposes. Each vehicle in the survey was assigned a new, unique vehicle identifier by OnStar before the data was processed and all links to the actual Vehicle Identification Numbers (VINs) were broken to ensure individual customer privacy. [Table 1](#) shows the key EPA Label metrics associated with these vehicles.

Table 1. Key EPA label metrics of Chevrolet Volt models from in-use data set and projected second generation Volt performance

Model Year	Generation	EPA Estimated Label Metrics		
		Charge Depleting Equivalent Fuel Economy (MPGe)	All-Electric Range (miles)	Charge Sustaining Fuel Economy (MPG)
2011	First Gen	93	35	37
2012	First Gen	94	35	37
2013 - 2015	First Gen	98	38	37
2016	Second Gen	102 GM Estimated	50 GM Estimated	41 GM Estimated

The vehicle trip data collected on each key cycle was as follows:

- Charge depleting vehicle miles using electricity only
- Vehicle odometer for total vehicle miles
- Amount of gasoline consumed

The vehicle charge event data collected was as follows:

- Time of day
- Charge status indicator
- Charge energy provided to the vehicle at the input to the On-Board Charge Module (OBCM) (AC kWh)
- Charge duration and charging power level were calculated from the charge energy and time of day data

This vehicle data was also used to project the performance of the second generation Volt. Multiple enhancements including a new 1.5L engine and higher energy, lighter weight battery pack contribute to the second generation Volt's improvements in all-electric range, charge sustaining fuel economy and mpg-e. The all-new second generation Volt to debut as MY2016 is projected to achieve more than 30% increase in all-electric range to 50 miles and 41 mpg once the battery is depleted [8].

In addition to analyzing the in-use data from the Chevrolet Volt vehicles described above, additional travel survey data is explored to make comparisons to other types of electrified vehicles. In particular, The Southern California Association of Governments (SCAG) Regional Travel Survey (RTS) [9] documented vehicle speed versus time traces from 621 vehicles in the Southern California area. In a previous study [7], this data was processed to evaluate the "power intensity" (energy used divided by distance driven) of real-world driving and to predict the number of initial engine starts under these driving conditions for conventional, HEV, PHEV and E-REV vehicles. From that study, it was predicted that an E-REV with 8 kW-hrs of useable electrical energy would have approximately 28% of the conventional vehicle's initial engine starts. With the first generation Chevrolet Volt real-world data, those initial engine start predictions can now be validated against the actual initial engine starts, predictions for the second generation Volt initial engine start performance can be made, and further comparisons to conventional and plug-in hybrid vehicles can be studied.

IMPACT OF EV RANGE ON INITIAL ENGINE STARTS AND ALL-ELECTRIC MILES FOR E-REVS

Analysis Method

Two key metrics were evaluated to quantify the relative impact of EV range on the ability of an E-REV to perform all-electric driving, reduce petroleum consumption, and eliminate initial engine starts (i.e. "cold starts") and associated criteria emissions. The first metric, percent of all-electric miles (also referred to as electric vehicle miles travelled (eVMT)), represents the percentage of total miles travelled that were driven purely using electrical energy from the grid. For EREVs, this metric is analogous to the Utility Factor and is directly related to the petroleum displaced [10]. The percent of all-electric trips (eTrips) is an additional metric used to provide insight into the amount of initial engine starts and the associated criteria emissions that are avoided through the use of a particular E-REV. This can be understood as the percent of trips taken where the internal combustion engine was not started and therefore zero fuel was used.

In addition to calculating eVMT and eTrips for the first generation Volt directly from the customer usage data, a range sensitivity analysis was completed for these metrics using two scenarios. First, the common assumption used for generating EPA fuel economy labels and other regulatory work of one full battery charge per driven day that is generally expected to occur at night while the vehicle is at home so that each vehicle begins the day with a full charge is studied [10]. As has been observed in other studies [11], this data set also showed the average Chevrolet Volt customer actually charges their vehicle more than once per day. To comprehend this increased number of charge events and quantify the benefit of this additional charging, the one charge per day scenario is extended to include the additional battery energy acquired from daytime opportunity charging. By taking advantage of these daytime charging opportunities, Chevrolet Volt customers effectively increased their daily all-electric range beyond the estimated label values.

In order to estimate the number of miles the vehicle would drive for a given amount of battery charge energy, the vehicle charge event data which contained the charge energy provided to the vehicle at the input to the OBCM was adjusted to account for the charge cord set and charge port losses, which was assumed to be 99% [12]. With the charge energy now in terms of AC wall energy, the label charge depleting energy consumption was used to estimate the equivalent electric miles for a given charge amount ultimately resulting in an effective daily all-electric range.

The effective daily all-electric range varies by day for each vehicle based on actual customer charge data. The label and effective range are compared against each vehicle's total miles driven for each day of the one year study to determine the all-electric miles potential for that driven day [11]. From this, the percent of all-electric miles can be determined. To complete the sensitivity study of range impact on percent of all-electric miles, the base label range was varied while maintaining the daytime charge behavior as it was observed in the customer charge data. Therefore, any changes in customer charging behavior with varying levels of range capability are not reflected as this was considered outside of the scope of this study.

Finally, to predict the percent of all-electric trips, the vehicle trip and charge data were sorted and combined into a single data set. Each vehicle was assumed to start the day with a full battery charge in alignment with the one charge per day assumption and a running available charge depleting range was calculated after each trip and charge event. Therefore, daytime charging is included by considering all charge events between the first and last trip of the day. If a trip resulted in the available charge depleting range to become zero or the available range was zero prior to beginning a trip, then an internal combustion engine start would have occurred on that trip. Because this study was most interested in the initial engine starts for each trip, which would be a cold start, it sufficed to know at least one engine start would occur on a single trip. The total number of engine starts were not evaluated.

Results

Figure 1 illustrates three scenarios. The dashed line evaluates the impact of varying levels of charge depleting range on the percent of miles that could be travelled all-electrically based on the driving behavior of the Chevrolet Volt vehicles in this data set if each vehicle was charged once per day. Studies have shown the average charge events per day for Volt drivers exceeds one [11], so the solid blue line takes both the driving and charging behavior of these E-REV customers into account. It should also be noted that when analyzing each charge depleting range, the range value was held as a constant value, which prevents a vehicle from over achieving that set range. In real world operation, the achieved charge depleting range varies with driving conditions. In moderate climates with efficient driving behaviors, drivers of the first generation Chevrolet Volt have been able to attain ranges greater than the estimate which provides an additional increase in eVMT. The bold green line in Figure 1 accounts for this additional improvement in range and the benefit from daytime charging.

This Chevrolet Volt study included vehicles from MY11-14 which had an EPA estimated all-electric range of 35-38 miles depending on model year. These Volt drivers were able to travel 74% of their total miles all-electrically without requiring the ICE's support. To study the impact of CD range on eVMT, the raw data was re-processed with varying levels of range. It was found that if a 35-38 mile range was strictly enforced while maintaining observed charge behavior, the all-electric miles would be approximately 66%-68%. With actual data showing 74% miles electrically, this suggests these drivers are achieving ranges that exceed EPA estimates near 45 miles.

Accounting for an additional 10% of miles travelled without the use of fuel, daytime opportunity charging also had a significant impact in increasing electric mileage as can be seen by the difference between the dashed and solid line. By charging more frequently than once per day, driving efficiently, and travelling shorter distances, Chevrolet Volt customers exceeded the Fleet Utility Factor (FUF) estimated from 2001 National Household Travel Survey data by 5 percentage points.

In addition to confirming the first generation Chevrolet Volt provides substantial petroleum displacement through 74% all-electric driving, this in-use operating data was used to predict the second generation Volt performance. With 50 miles of EPA estimated label all-electric range, the second generation Volt is projected to complete 80% of total miles driven using electricity. Considering this in combination with the improved fuel economy of 41 mpg, 25% less petroleum is projected to be used from the already reduced usage of the first generation Volt assuming the same driving and charging behavior as observed in this subset of vehicles and a similar in-use range increase over the EPA label estimates.

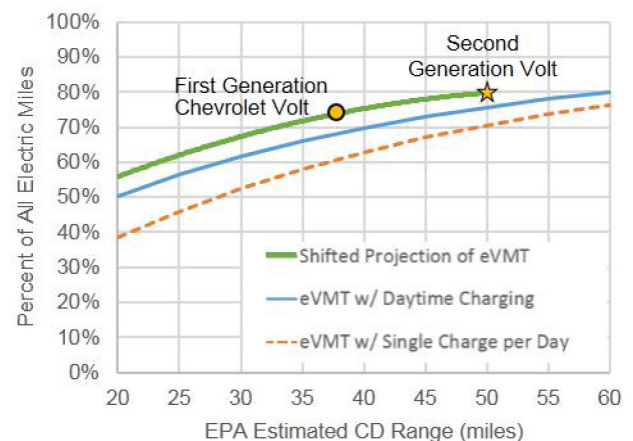


Figure 1. Estimated percentage of total miles that could be driven with electricity only (no fuel required) (aka UF) versus EPA Estimated CD Range (miles)

Idaho National Laboratory (INL) has also tracked and reported in-use operating data for plug in vehicles through involvement in the EV Project and other government studies [11,13]. A 2014 study of on road plug in hybrid electric vehicles also showed Chevrolet Volt customers participating in the EV Project exceeded the FUF calculated from the 2001 National Household Travel Survey. The INL report also provided performance results for other plug in vehicles currently on the market including four PHEVs which were able to achieve 16%, 22%, 33%, and 36% of vehicle miles travelled.