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Electric Vehicle Life Cycle Cost Analysis

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EVTC

Electric Vehicle Transportation Center

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EVTC Project 6 – Electric Vehicle Life Cycle Cost Analysis

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The objective of the Electric Vehicle Life Cycle Cost Analysis project was to compare total life cycle costs of electric vehicles, plug-in hybrid electric vehicles, hybrid electric vehicles, and compare with internal combustion engine vehicles. The analysis has considered both capital and operating costs in order to present an accurate assessment of lifetime ownership costs. The analysis also included vehicle charging scenarios of photovoltaic (solar electric) powered charging and workplace charging. The work was conducted by Richard Raustad, Principle Investigator, and Philip Fairey of the Florida Solar Energy Center.

Final Research Project Report

Electric Vehicle Life Cycle Cost Analysis

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January 2017

Abstract

This project compared total life cycle costs of battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), hybrid electric vehicles (HEV), and vehicles with internal combustion engines (ICE). The analysis considered capital and operating costs in order to present an equal comparison of differing vehicles. The analysis also included photovoltaic (PV) and workplace charging options. The overall goal was to define the total vehicle cost of ownership over 5, 10, 15, and 20 year life expectancies. The developed life cycle cost computer program will allow any individual to compare life cycle costs of any vehicle.

Research Results

This project had three objectives as follows:

1. To develop a life cycle cost (LCC) model for automotive vehicles that accurately evaluates electric vehicle types,
2. To allow for any user to download and use the developed LCC model, and
3. To evaluate photovoltaics (PV) as a power option for electric vehicles.

The details of the developed LCC model and it applications were presented in an EVTC technical report -- Raustad, R., Fairey, P. (2014). "Electric Vehicle Life Cycle Costs Assessment." Electric Vehicle Transportation Center, FSEC-CR-1984-14. For completeness of this document the EVTC report is presented in Appendix 1.

The developed LCC model will compare ownership costs, on a present value and an annual cost basis, of plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) as compared to conventional internal combustion engine (ICE) vehicles for an average number of miles driven per year. The analysis used actual 2014 cost values for 16 production vehicles all sold in the United States. The LCC model includes the vehicle costs of purchase price with federal incentives, if any, salvage value, fuel consumption (electricity and liquid fuel), tires, insurance, maintenance, state tax and financed interest payments. The vehicles considered are hybrid electric vehicles, PHEVs, and BEVs as compared to ICEs using gasoline, ethanol, or diesel. It is noted that the traction battery replacement costs for electric vehicles were difficult to ascertain, but were included in the analysis by replacing the batteries in the 11th year in order to investigate the battery impact on overall costs. Economic factors used in the LCC include differing rates for inflation, discount, and fuel escalation and battery degradation in the electric vehicles to account for battery energy depletion over time. The LCC was performed over a 5-, 10-, or 15-year lifetime period.

Results were presented for the specific case of 12,330 miles driven per year and for the selected economic factors. These LCC results show that even with higher first costs, battery powered vehicles are lower in cost to conventional ICE vehicles. Using the two lowest-cost variant vehicles, a Nissan Leaf and a Hyundai Elantra, the Leaf's 5-year annual cost including salvage value is $5,360/year compared to the Hyundai at $7,076/year. The results for the 10-year lifetime show the Leaf at $4,683/year and the Hyundai at $6,040/year. These results are primarily due to lower fuel cost of electricity versus gasoline, which for the Leaf is $3,919 while the Hyundai gasoline cost is $10,931 for the 10-year period. A comparison of two other popular plug-in electric vehicles, the Chevrolet Volt and Toyota Prius, shows higher values for both vehicles; over a period of 10 years, the Volt is $6,286/year and the Prius is $6,156/year.

The results for the case where the government incentive of $7,500 is deleted also show the LCC values for a Leaf over a 10-year period is less than the Hyundai when salvage value is considered. The Leaf is $5,369/year compared to the Hyundai at $6,040/year. For a 5-year period, this result is also true where the Leaf is $6,733/year and the Hyundai is $7,076/year.

The results for the case where the vehicles are owned for 5 years are shown in the below Figure 1. These results show the lowest cost option is the Chev Spark followed by the Nissan Leaf.

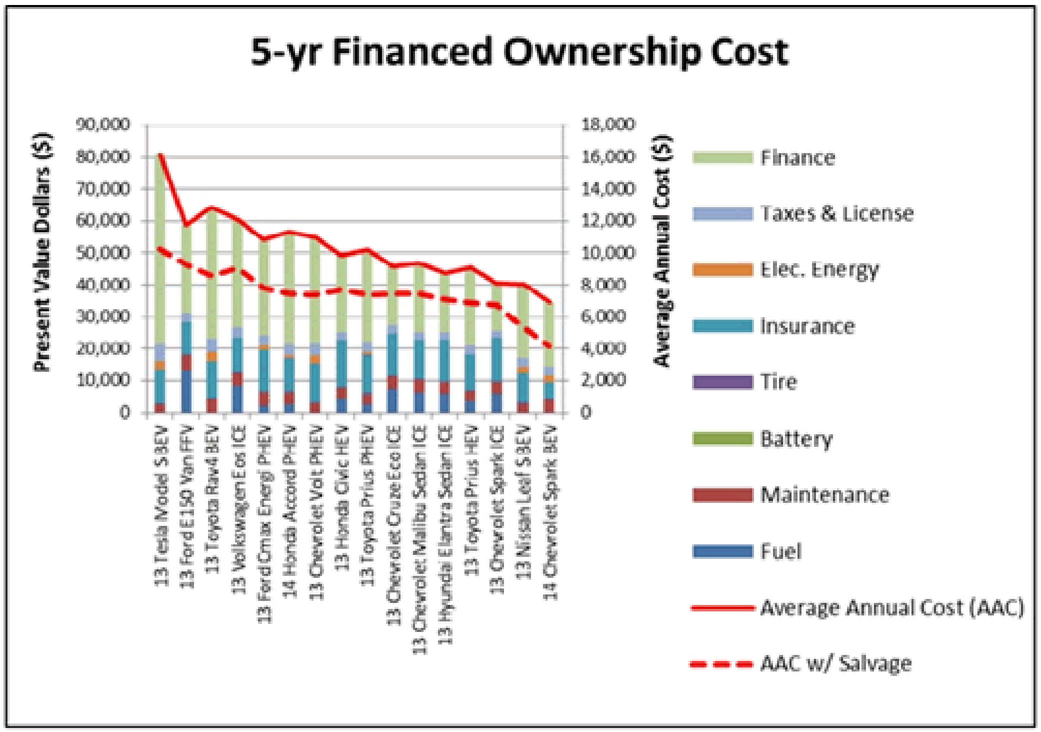

Figure 1. 5-Year Financed Ownership Cost

Impacts/Benefits

The results provide consumers with the requisite information needed to make an informed financial decision regarding the purchase of personal transportation using LCC cost comparisons. Although electric vehicle technology is higher in first cost, the operating and maintenance cost savings provide lower life cycle costs than conventional vehicles (for those vehicles that are reasonably priced). The analysis also shows that a PV system of about 4 kW in size would supply the required electrical energy for an EV traveling the yearly miles assumed.

Appendix 1 -- Raustad, R., Fairey, P. (2014). "Electric Vehicle Life Cycle Costs Assessment." Electric Vehicle Transportation Center, FSEC-CR-1984-14

Electric Vehicle Transportation Center

Electric Vehicle Life Cycle Cost Assessment

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I. Abstract

This report has three objectives: to develop a life cycle cost (LCC) model for automotive vehicles that accurately evaluates electric vehicle types, to allow for any user to download and use the developed LCC model, and to evaluate photovoltaics (PV) as a power option for electric vehicles. The most important part of the work is the LCC model that compares ownership costs, on a present value and an annual cost basis, of plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) as compared to conventional internal combustion engine (ICE) vehicles for an average number of miles driven per year. The analysis uses actual cost values for 16 production vehicles all sold in the United States. The LCC model includes the vehicle costs of purchase price with federal incentives, if any; salvage value; fuel consumption (electricity and liquid fuel); tires; insurance; maintenance; state tax; and financed interest payments. The vehicles considered are hybrid electric vehicles, PHEVs, and BEVs as compared to ICEs using gasoline, ethanol, or diesel. It is noted that the traction battery replacement costs for electric vehicles are difficult to ascertain, yet they are included in the analysis by replacing the batteries in the 11th year in order to investigate the battery impact on overall costs. Economic factors used in the LCC include differing rates for inflation, discount, and fuel escalation and battery degradation in the electric vehicles to account for battery energy depletion over time. The LCC is performed over a 5-, 10-, or 15-year lifetime period.

For the specific case of 12,330 miles driven per year and for the selected economic factors, the LCC results show that even with higher first costs battery powered vehicles are lower in cost to conventional ICE vehicles. Using the two lowest-cost variant vehicles, a Nissan Leaf and a Hyundai Elantra, the Leaf's 5-year annual cost including salvage value is $5,360/year compared to the Hyundai at $7,076/year. The results for the 10-year lifetime show the Leaf at $4,683/year and the Hyundai at $6,040/year. These results are primarily due to lower fuel cost of electricity versus gasoline, which for the Leaf is $3,919 while the Hyundai gasoline cost is $10,931 for the 10-year period. A comparison of two other popular plug-in electric vehicles, the Chevrolet Volt and Toyota Prius, shows higher values for both vehicles; over a period of 10 years, the Volt is $6,286/year and the Prius is $6,156/year.

The results for the case where the Leaf government incentive of $7,500 is deleted also show the LCC values for a 10-year period that the Leaf is less than the Hyundai when salvage value is considered. The Leaf is $5,369/year compared to the Hyundai at $6,040/year. For a 5-year period, this result is also true where the Leaf is $6,733/year and the Hyundai is $7,076/year.

The other objective of the work is the LCC simulation program that can be downloaded and used by any individual with his or her own miles driven and vehicle cost data. The program with the input for three example vehicles is presented. The third objective is the application of PV power, which was assessed to determine the size of a PV array located in Florida that would completely supply power for electrical needs of a vehicle using a traction battery. For a 10-year period, the array size was determined to be 2.38 kW for the Nissan Leaf.

II. Introduction

Electric vehicles (PEV), defined in this report as either plug-in or total battery electric, have gained widespread attention since the introduction of these vehicles only four years ago. These vehicles were of course not the first of their kind [1], but given sharp increases in fuel prices PEVs have certainly captured the attention of the general public. Sales of PEVs have increased dramatically and have outpaced the rate and number of hybrid vehicle sales over their introductory years. There are currently thirteen PEV manufacturers producing one or more models. This has expanded consumer choice to the current 18 PEV options. The purchase price of PEVs is greater than conventional or even hybrid vehicles due to the traction battery size.

Federal incentives have helped reduce purchase price associated with PEVs. Beginning in 2010, a federal tax credit [2] of $2,500 to $7,500 became available for purchasers. For vehicles purchased after December 31, 2009, a tax credit of $2,500 is available for a vehicle that draws energy from a traction battery of at least 5 kilowatt hours (kWh) capacity with an additional credit of $417 for each kWh of battery capacity in excess of 5 kWh. The total allowable credit is $7,500 for a vehicle with a battery size of 16.05 kWh or greater. The credit begins to phase out for a manufacturer when 200,000 qualifying vehicles have been sold for use in the United States. As of this report's publication date, there are no published congressional actions to reduce or eliminate the tax credit, and no manufacturer is approaching the 200,000 cumulative vehicles sales figure. For additional information, see IRS Notice 2009-89. A list of qualified vehicles is available in Appendix A.

Many vehicle cost models have been used to predict total life cycle costs (LCC) for transportation vehicles. Two of these models are the U.S. Department of Energy's (DOE) vehicle cost calculator and EPRI's total cost of ownership model [3, 4]. The U.S. Department of Energy's vehicle cost of ownership calculator is a web-based tool that compares a wide range of vehicle types. The model includes cost of fuel; operating and maintenance costs; and insurance, license, and registration fees. However, the DOE calculator does not include cost of a replacement battery for PEVs because of uncertainty in expected life and future cost associated with battery replacement.

Alexander and Davis [4] at EPRI reported that for PEVs, driving patterns and commute distance play a crucial role in deciding if the switch to a PEV makes economic sense. In their analysis, the cost of tire replacements, insurance, repair costs, and salvage value were not included due to lack of data or modeling judgment. These are not necessarily bad modeling assumptions given that newer vehicles do not have a sufficient history to provide reliable cost data for repairs and salvage value.

Although the purchase price of PEVs is perceived to be high compared to conventional counterparts, the operating and maintenance costs are low compared to even the most economical compact cars. Given the current markets, state and federal incentives, and lower operating and maintenance costs, what are the true LCCs of PEVs? This study investigates this question along with other economic factors that impact the LCCs of vehicle ownership.

III. Model Assumptions

3.1 Vehicle Information

The vehicles chosen for analysis are conventional internal combustion engine (ICE) or flex fuel (FFV), plug-in hybrid electric (PHEV), hybrid electric (HEV), and battery electric (BEV) in today's marketplace. The model year is selected as 2013; however, for two of the selected vehicles that were not yet available in 2013, the 2014 year model was used. High-end luxury and low-cost automobiles are included for comparative purposes. The following vehicle information is used as input to the LCC model.

Table 1 shows the manufacturer's suggested retail price (MSRP), as reported by Edmunds.com [5] at the time the analysis was conducted. These values are used as the vehicle purchase price as well as the range and fuel efficiencies from Edmunds. Note the traction battery size is also included for PEVs.

Table 1. Vehicle Information for LCC Analysis

Year	Make	Model	MSRP	Type	Range Elec./Ext.	MPGe / MPG	Battery (kWh)
2013	Tesla	Model S	$ 69,900	BEV	230 / -	120 / -	60
2013	Toyota	Rav4	$ 50,660	BEV	107 / -	76 / -	27.4
2013	Chevrolet	Volt	$ 42,355	PHEV	38 / 380	98 / 37	16.5
2014	Honda	Accord	$ 40,570	PHEV	13 / 570	115 / 46	4.4
2013	Volkswagen	Eos	$ 35,840	ICE	- / 350	- / 26	-
2013	Ford	CMax Energi	$ 35,340	PHEV	19 / 522	88 / 36	7.6
2013	Toyota	Prius	$ 33,113	PHEV	12 / 540	95 / 50	4.4
2013	Nissan	Leaf S	$ 31,415	BEV	75 / -	115 / -	24
2013	Ford	E150 Van	$ 29,150	FFV	- / 495	- / 15	-
2014	Chevrolet	Spark	$ 28,570	BEV	82 / -	119 / -	21
2013	Toyota	Prius	$ 25,861	HEV	- / 500	- / 50	1.3
2013	Honda	Civic	$ 25,150	HEV	- /500	- / 43	1.3
2013	Chevrolet	Malibu Sedan	$22,960	ICE	- / 482	- / 28	-
2013	Hyundai	Elantra Sedan	$ 19,685	ICE	- / 300	- / 33	-
2013	Chevrolet	Cruze Eco	$ 19,440	ICE	- / 300	- / 32	-
2013	Chevrolet	Spark	$ 15,860	ICE	- / 300	- / 33	-

Note: MPGe, miles per gallon equivalent; MPG, miles per gallon

3.2 Daily Mileage

In order to perform meaningful comparisons and calculations, the number of miles per year that the vehicle is driven must be specified. For this analysis, two cases were considered:

1. An average U.S. DOT daily mileage rate was evaluated and then used.
2. Comparison of vehicles for the cases of driving 10,000, 20,000, and 30,000 miles per year.

Average Daily Mileage for Calculations

Driving statistics chosen for this study were taken as the average number of miles (12,330 miles) from the alternative fuels data center [6]. These miles are shown in Table 2. The mileage inputs are divided into local travel and commute travel. Local daily travel of 33.9 miles represents various household errands. Commute daily travel of 34 miles represents regular travel to and from work and weekday errands. Travel is further divided into the percentage of city and highway driving. For flex-fueled vehicles, the volume-based percent flex fuel used is also a model input. Taken together, these daily trip statistics represent the average driver traveling a total annual mileage of 12,330 miles per year.

The first five rows are model inputs while the last four rows are calculated. An input for the number of PEV charges per day is included where electric-only driving range would be doubled when charging twice per day or halved if charging every other day. This study assumed that vehicles would be charged once per day.

Table 2. Driving Statistics

Driving Statistics			
Local		Commute	
Miles:	33.9	*Miles*:	34
Days:	118	*Days*:	245
Percent City:	50.0%	*Percent City*:	75.0%
% Flex:	80.0%	*% Flex*:	10.0%
Charges per Day:	Once	*Charges per Day*:	Once
City:	2000.0	*City*:	6247.5
Highway:	2000.0	*Highway*:	2082.5
Maximum Daily Commute (mi):		34	
Annual Driving Distance (mi):		12330	

Note: The descriptors in italics are used in subsequent appendices.

3.3 Calculating Daily Driving Distances

For vehicle types other than PHEVs, the daily local or commute driving distances are taken directly from Table 2. For PHEV cars, the total electric driving range is used to determine fuel use. The difference between the daily driving distance and the distance traveled on electric energy provides the daily liquid fuel driving distance. Thus, the PHEV case is shown in Table 3. The impact of battery degradation is included in this study. Battery degradation will increase the long-term fuel needs by requiring more liquid fuel.

Table 3. PHEV Annual Mileage Calculations

Fuel Efficiency Data:	Efficiency	Mileage	Total Miles:
Gas City MPG (*MPGc*):	42	965	
Gas Highway MPG (*MPGh*):	38	475	1440
Electric City kWh/mi:	0.22	7283	
Electric Highway kWh/mi:	0.26	3608	10890
Flex Fuel City MPG (*MPGFFc*):	14	0	
Flex Fuel Highway MPG (*MPGFFh*):	20	0	0
Total:			12330

Note: The values in Table 3 emulate the Alternative Fuels Data Center Vehicle Cost Calculator fuel volume calculations. Mathematical calculations for each category's mileage are shown in Appendix B.

3.4 Calculating Electric, Gas, or Flex Fuel Consumption

The LCC model calculates gas or diesel, flex fuel, and electricity fuel consumption by using the efficiency values of Table 1 and the mileage of Table 2. The special case of a PHEV requires the use of the efficiency and mileage values given in Table 3. More-detailed calculations using operating efficiency are described in Table 6 (Section IV). In order to understand the type of calculations performed, an example calculation for a PHEV vehicle starting in Year 1 and ending in Year 20 is presented in Table 4.

Note in Table 4 that the battery range in energy and miles (columns 4 and 5) is shown to decrease with time due to battery degradation. The calculations of fuel consumption per year are completed for each vehicle type and in the top left portion show annual city and highway gas, flex, or electric use based on the vehicle's fuel type. The LCC model will select the required inputs from Table 2. Using the previous example for a gasoline-supplemented PHEV assuming an electric driving range of 30 miles, the annual gas consumption for city driving would be the quotient of 965 miles and 42 mpg city fuel efficiency yielding a total of 22.97 gallons of fuel per year. Annual highway fuel use is calculated similarly as 12.5 gallons. As a check, the fuel use associated with local and commute driving is also calculated to ensure that fuel use totals for each calculation method agree (i.e., city/highway vs. local/commute). The local and commute calculations are somewhat more involved and are shown in Appendix C in equation form.

The top center of the table shows the simplified calculations for daily electrical energy use calculated using the driving statistics shown in Table 2 and the electrical fuel efficiency shown in Table 3 (e.g., Local Electric Energy = 33.9 miles * 50% city * 0.22 kWh/mi + 33.9 miles * (1 - 50% city) * 0.26 kWh/mi = 8.14 kWh).

The top right of the table shows simple calculations (e.g. *Local Miles* * *Local Days*) for total mileage verification and efficiency for PHEV and BEV only as total energy used for year 1 divided by total mileage.

Table 4. Electric, Gas, or Flex Fuel Consumption Calculations for PHEV Vehicle Exam

PHEV Fuel Calculations	Gas (gal.)	Flex (gal.)	Elec (kWh)
City:	23.0	0.0	1602.2
Highway:	12.5	0.0	938.0
Local:	11.5	0.0	849.6
Commute:	23.9	0.0	1690.5
Total Fuel Use:	35.5	0.0	2540.1
check:	35.5	0.0	2540.1

Local			Commute		
Battery Miles	Shortage Miles	Electric Energy	Battery Miles	Shortage Miles	Electric Energy
33.9	0.0	8.1	34.0	0.0	7.8

Total EV Miles:

Co

PHEV/BEV Eff

Year	Fuel Gas/Diesel Cost	Flex E85 Cost	Battery Range kWh	Battery Range miles	Local: Daily Energy Used kWh	Local: Daily Shortage Energy kWh	Local: Total Electric Energy kWh	Commute: Daily Energy Used kWh	Commute: Daily Shortage Energy kWh	Commute: Total Electric Energy kWh	Annual Totals: Local Energy Used kWh	Annual Totals: Commute Energy Used kWh
1	$114	$0	24.0	30.0	7.2	0.0	7.2	6.9	0.0	6.9	850	1691
2	$133	$0	23.5	29.4	7.1	0.0	7.1	6.8	0.0	6.8	833	1657
3	$153	$0	23.0	28.8	6.9	0.0	6.9	6.6	0.0	6.6	816	1624
4	$173	$0	22.6	28.2	6.8	0.0	6.8	6.5	0.0	6.5	800	1591
5	$193	$0	22.1	27.7	6.6	0.0	6.6	6.4	0.0	6.4	784	1559
6	$214	$0	21.7	27.1	6.5	0.0	6.5	6.2	0.0	6.2	768	1528
7	$234	$0	21.3	26.6	6.4	0.0	6.4	6.1	0.0	6.1	753	1498
8	$256	$0	20.8	26.0	6.3	0.0	6.3	6.0	0.0	6.0	738	1468
9	$277	$0	20.4	25.5	6.1	0.0	6.1	5.9	0.0	5.9	723	1438
10	$299	$0	20.0	25.0	6.0	0.0	6.0	5.8	0.0	5.8	708	1409
11	$135	$0	24.0	30.0	7.2	0.0	7.2	6.9	0.0	6.9	850	1691
12	$158	$0	23.5	29.4	7.1	0.0	7.1	6.8	0.0	6.8	833	1657
13	$181	$0	23.0	28.8	6.9	0.0	6.9	6.6	0.0	6.6	816	1624
14	$205	$0	22.6	28.2	6.8	0.0	6.8	6.5	0.0	6.5	800	1591
15	$229	$0	22.1	27.7	6.6	0.0	6.6	6.4	0.0	6.4	784	1559
16	$253	$0	21.7	27.1	6.5	0.0	6.5	6.2	0.0	6.2	768	1528
17	$278	$0	21.3	26.6	6.4	0.0	6.4	6.1	0.0	6.1	753	1498
18	$303	$0	20.8	26.0	6.3	0.0	6.3	6.0	0.0	6.0	738	1468
19	$328	$0	20.4	25.5	6.1	0.0	6.1	5.9	0.0	5.9	723	1438
20	$354	$0	20.0	25.0	6.0	0.0	6.0	5.8	0.0	5.8	708	1409

The far right of the Table 4 body shows PHEV gas miles traveled using liquid fuel after depleting energy stored in the traction battery. Since a battery degradation factor is used to adjust traction battery range, these mileage calculations are used in the detailed analysis instead of the fuel use calculations at the top left of the table.

Total annual electric energy use and liquid fuel costs are then calculated. Fuel costs for gasoline, diesel, and flex fuel are straightforward calculations based on the total volume of fuel consumed and the price per gallon for the specific fuel type. Daily local and commute energy use are calculated in a manner similar to liquid fuel where the distance, percent city, and efficiency are used to determine the amount of energy consumed for both local and commute travel. For BEV, if the trip length exceeds the traction battery range, a daily energy shortage value is calculated. Daily electrical energy shortage is calculated only for BEV vehicle types and assumes that the vehicle must charge somewhere along the travel path to complete the journey.

3.5 Vehicle Trade-in or Salvage Value

The vehicle trade-in or salvage value can be difficult to ascertain given that different vehicle models depreciate at different rates and future material prices vary. The vehicles studied here were entered in the Edmonds.com True Cost to Own® model to determine any noticeable trend in trade-in estimates. Given the vehicles total cash price, as reported on the Edmunds.com website for Orlando, Florida, the percent annual depreciation was calculated for the first 5 years of vehicle ownership. The largest difference in depreciation occurs during the first year of ownership where depreciation rates vary from 17% to 29% for the vehicles studied. For years 2 through 4, the depreciation rates are much more similar. At year 5, the depreciation rates are nearly equal and range between 5% and 8% for all vehicles. The cumulative depreciation also shows that the out-year depreciation rate is very similar among different vehicle types as indicated by the nearly parallel lines offset mainly by the first-year differences. For this study, the average depreciation rate is used and is highlighted in Figure 1. Appendix D shows an example data set used for all vehicles.

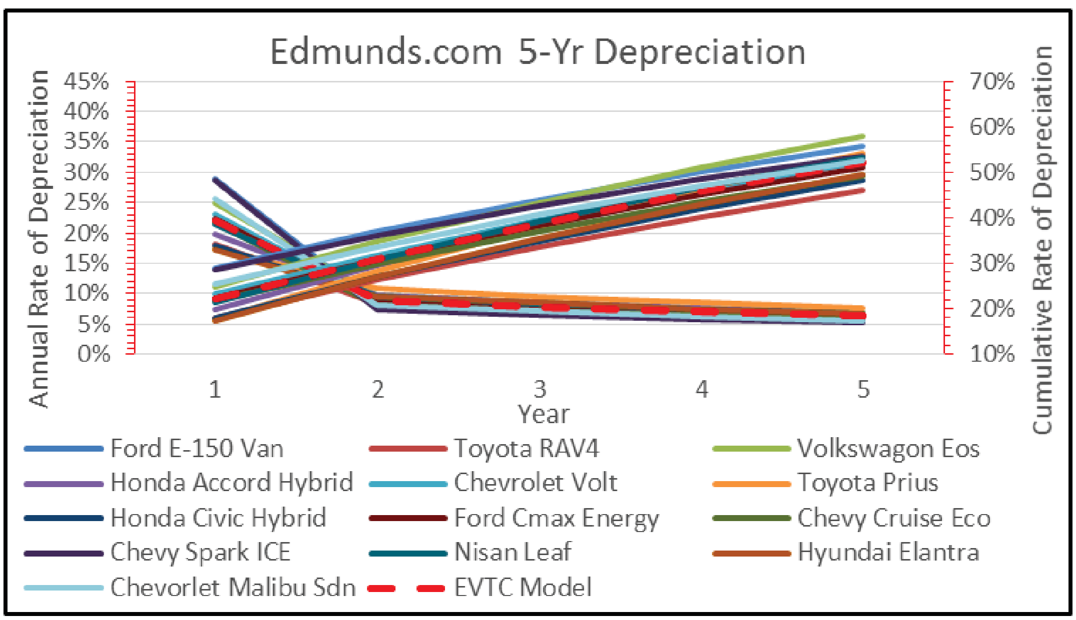

Figure 1. Vehicle Depreciation Rate over the First 5 Years of Ownership

Using the previously described average depreciation rates, the out-year depreciation rates were assumed to gradually decrease to a point where 1.5% of the purchase price remained after 20 years of ownership (e.g., $450 for a $30,000 vehicle purchase price). This gives a potential advantage to expensive vehicles and a likely disadvantage to low-cost vehicles, given that the end-of-life salvage value is actually based on scrap material prices at the time of salvage. This advantage or disadvantage is relatively small compared to the LCCs of transportation vehicles and is not deemed significant in this analysis. Figure 2 shows the vehicle depreciation curve and corresponding equation used in the calculations.

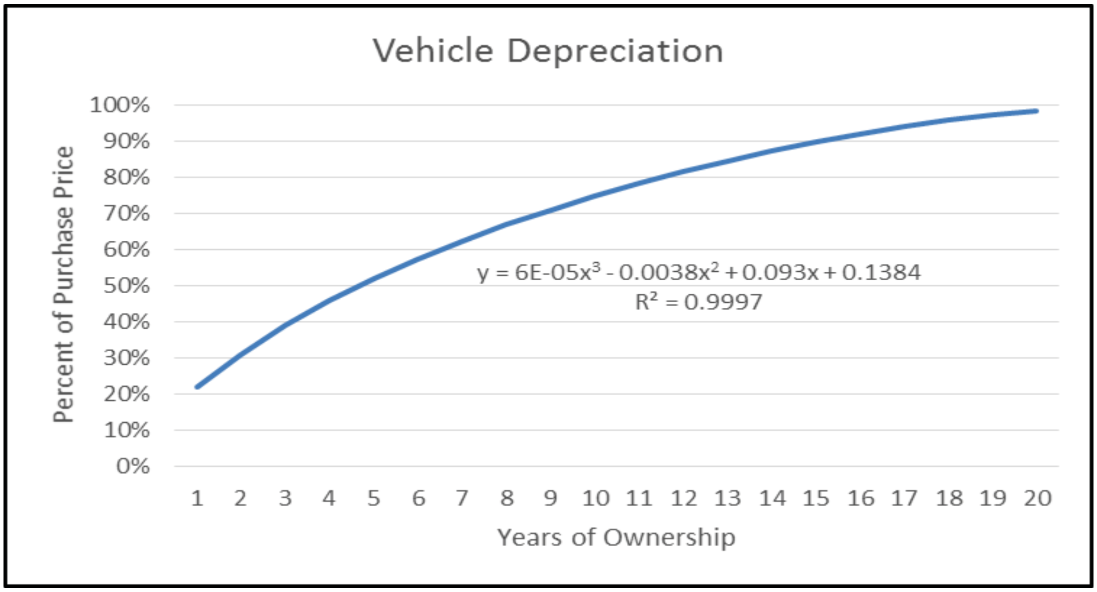

Figure 2. LCC Vehicle Depreciation Assumption

3.6 Traction Battery Degradation

For PHEVs and BEVs, the replacement cost of the traction battery can have a significant impact on LCC. Some analysts have made assumptions that the traction battery may not need replacement during the useful life of the vehicle [7] while others assume the manufacturer's warranty sufficiently characterizes the expected battery lifetime [8]. A review of these and other estimates of battery life leads to a conclusion that a traction battery is viable for use in electrified vehicles with advanced battery management systems for a period exceeding 4,400 battery charge/discharge cycles [9]. This number of charge/discharge cycles would translate to a battery life of 12 years for a vehicle that required daily charging. For analysis purposes, an 11-year battery life will be used to compare over a 15-year ownership period (in one result, the battery is replaced in the 11^{th} year).

3.7 Economic Factors

The LLC economic factors used include the general inflation rate, the fuel escalation rates, the monetary discount rate, and a purchase price interest rate covering the car loan. The economic factors and their selected values are shown in Table 5. These factors are well described in literature.

Table 5. Economic Impact Factors

General Inflation Rate	2.53 %
Discount Rate	4.53 %
Vehicle Purchase Rate	4.04 %
Fuel Escalation Rates:	
Gasoline	1.7 %
Ethanol	1.7 %
Electricity	3.42 %

3.8 Other Operating Costs

The cost of maintenance and insurance are difficult to quantify for various reasons. Some vehicle owners may perform regular maintenance on their own vehicles while other owners rely on local repair shops or dealerships for regular or selective maintenance. The cost of insurance is also highly volatile and depends both on the owner's driving record, the number of vehicles insured, the owner's accident rate, and the type of vehicle and its first cost. For this study, the data provided by the Edmunds.com website for the city of Orlando, Florida is used for these cost estimates.

Costs associated with tire replacement are included at the time the tires are actually replaced as opposed to including an annual cost of tire per mile of operation as is done in some analyses. Maintenance costs are annualized per year in order to simplify the model. Edmunds does provide varying maintenance costs over a 5-year period; however, these costs are unknown as vehicle age progresses. For this reason, the maintenance costs were reduced by the cost of tires and then averaged over a 5-year period to yield an annual maintenance cost estimate. This value was used in this study for each year.

Battery costs are still the most difficult to accurately determine given low number of years of data. Future costs depend on breakthrough technology and investment in manufacturing. With advances in battery technology and manufacturing, costs will ultimately decline. But when and by how much? For this analysis, it was assumed that current costs are $400/kWh and would decline to $128/kWh in 20 years. This is a very conservative estimate given the DOE EV Everywhere Grand Challenge [10] goals for battery technology of reducing costs to $125/kWh by 2022. Regardless of the initial battery cost selected for this study, the estimated battery cost after 11 years used in this study is $180/kWh and is well above the DOE cost target. Figure 3 provides the equation used to estimate the battery cost. Note that the PEV batteries are replaced in the 11th year.

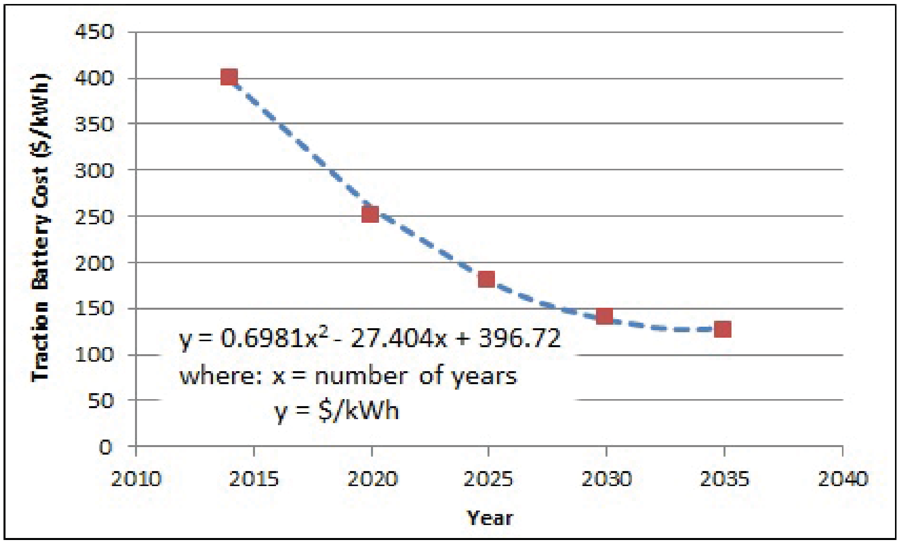

Figure 3. PEV Traction Battery Cost Estimate

It is noted that the cost value associated with the core of the traction battery is not included when the traction battery is replaced at the end of the useful automotive life. The secondary useful life of a traction battery could potentially lower the LCC associated with PEVs; however, this area of usage is in its infancy and little is known about specific usages and related cost values.

The impact of increased fuel costs due to battery degradation for HEV models is not included in this study since changes in long-term fuel efficiency (i.e., city and highway MPG) over the anticipated battery life are not available.

Florida Metro Area fuel prices for Orlando, Florida were used as of September 30, 2014. This data shows regular, premium, and diesel fuel prices as $3.206, $3.648, and $3.686, respectively [11]. A Florida state average residential electric price of ¢11.42 per kWh is used for both local and commute travel.

IV. Results

Table 6 presents all vehicle parameters associated with each individual vehicle over the selected simulation period chosen for analysis. The LCC tool uses a template to perform all necessary calculations. This template and the information previously described are copied to a specific vehicle model worksheet where calculations are specific to each vehicle. The simulation results are then copied to a results worksheet where data can be compared across models. Section 4.4 of this report presents a complete list of all parameters and three example calculations.

The results are presented in two sections as follows:

1. Simulation results for vehicles traveling 12,330 miles/year.
2. Simulation results for vehicles traveling 10,000, 15,000, and 20,000 miles/year.

All simulation results use the same vehicle and economic parameters.

Table 6. LCC Model Inputs

Year	Make	Model	Type	Battery Cost	Battery Life*	Main.	Tires	Tire Mileage	City MPG	Hwy MPG	Fuel	City kWh/mi	Hwy kWh/mi	Flex Fuel City MPG
2013	Tesla	Model S	BEV	$24,000	12	$490	$450	50,000				0.36	0.35	
2013	Ford	E150 Van	FFV			$999	$450	50,000	13	17	Regular			9
2013	Toyota	Rav4	BEV	$10,960	12	$866	$450	50,000				0.43	0.46	
2013	Volkswagen	Eos	ICE			$803	$450	50,000	22	30	Diesel			
2013	Ford	CMax Energi	PHEV	$3,040	12	$849	$450	50,000	40	36	Regular	0.36	0.4	
2014	Honda	Accord	PHEV	$1,760	11	$834	$450	50,000	47	46	Regular	0.29	0.29	
2013	Chevrolet	Volt	PHEV	$6,600	12	$608	$450	50,000	35	40	Premium	0.36	0.37	
2013	Honda	Civic	HEV	$520	12	$777	$450	50,000	44	44	Regular			
2013	Toyota	Prius	PHEV	$1,760	12	$714	$450	50,000	51	49	Regular	0.35	0.35	
2013	Chevrolet	Cruze Eco	ICE			$849	$450	50,000	22	34	Regular			
2013	Chevrolet	Malibu	ICE			$770	$450	50,000	25	36	Regular			
2013	Hyundai	Elantra Sdn	ICE			$643	$450	50,000	28	38	Regular			
2013	Toyota	Prius	HEV	$520	12	$761	$450	50,000	51	48	Regular			
2013	Chevrolet	Spark	ICE			$549	$450	50,000	28	37	Regular			
2013	Nissan	Leaf S	BEV	$9,600	12	$823	$450	50,000				0.27	0.33	
2014	Chevrolet	Spark	BEV	$8,400	11	$490	$450	50,000				0.26	0.31	

* - Battery life number of years in this table is set to provide battery replacement in the 11th year of simulation.

Table 7. Simulation Results for a 2013 Nissan LEAF

	Simulation Results											
Year	Fuel	Maintenance	Battery Replacement	Tire Replacement	Insurance	Elec. Energy	Taxes &	PV Sales	Finance Charges	Financed Ownership Cost	Purchased Ownership Cost	Ve re va
2014	$ -	$ 549	$ -	$ -	$ 1,952	$ 430	$2,838	$ -	$ 9,276	$ 15,045	$ 37,184	$ 2
2015	$ -	$ 593	$ -	$ -	$ 2,052	$ 444	$ 61	$ -	$ (1,366)	$ 1,785	$ (4,349)	$ 1
2016	$ -	$ 608	$ -	$ -	$ 2,104	$ 460	$ 63	$ -	$ 6,134	$ 9,369	$ 3,235	$ 1
2017	$ -	$ 624	$ -	$ -	$ 2,157	$ 475	$ 65	$ -	$ 6,134	$ 9,455	$ 3,321	$ 1
2018	$ -	$ 639	$ -	$ 510	$ 2,212	$ 491	$ 66	$ -	$ 6,134	$ 10,053	$ 3,919	$ 1
2019	$ -	$ 656	$ -	$ -	$ 2,268	$ 508	$ 68	$ -	$ -	$ 3,499	$ 3,499	$ 1
2020	$ -	$ 672	$ -	$ -	$ 2,325	$ 526	$ 70	$ -	$ -	$ 3,593	$ 3,593	$ 1
2021	$ -	$ 689	$ -	$ -	$ 2,384	$ 544	$ 71	$ -	$ -	$ 3,688	$ 3,688	$
2022	$ -	$ 707	$ -	$ 563	$ 2,444	$ 562	$ 73	$ -	$ -	$ 4,350	$ 4,350	$
2023	$ -	$ 724	$ -	$ -	$ 2,506	$ 581	$ 75	$ -	$ -	$ 3,887	$ 3,887	$
2024	$ -	$ 743	$ 4,042	$ -	$ 2,569	$ 601	$ 77	$ -	$ -	$ 8,032	$ 8,032	$
2025	$ -	$ 762	$ -	$ -	$ 2,634	$ 622	$ 79	$ -	$ -	$ 4,097	$ 4,097	$
2026	$ -	$ 781	$ -	$ 623	$ 2,701	$ 643	$ 81	$ -	$ -	$ 4,829	$ 4,829	$
2027	$ -	$ 801	$ -	$ -	$ 2,769	$ 665	$ 83	$ -	$ -	$ 4,318	$ 4,318	$
2028	$ -	$ 821	$ -	$ -	$ 2,840	$ 688	$ 85	$ -	$ -	$ 4,433	$ 4,433	$
2029	$ -	$ 842	$ -	$ -	$ 2,911	$ 711	$ 87	$ -	$ -	$ 4,552	$ 4,552	$
2030	$ -	$ 863	$ -	$ 688	$ 2,985	$ 736	$ 89	$ -	$ -	$ 5,361	$ 5,361	$
2031	$ -	$ 885	$ -	$ -	$ 3,061	$ 761	$ 92	$ -	$ -	$ 4,798	$ 4,798	$
2032	$ -	$ 907	$ -	$ -	$ 3,138	$ 787	$ 94	$ -	$ -	$ 4,926	$ 4,926	$
2033	$ -	$ 930	$ -	$ -	$ 3,217	$ 814	$ 96	$ -	$ -	$ 5,058	$ 5,058	$
10 Year Average	$ -	$ 505	$ -	$ 79	$ 1,753	$ 392	$ 318	$ -	$ 2,305	$ 5,352	$ 5,367	
NPV: 10 Years	$ -	$ 5,054	$ -	$ 787	$ 17,532	$ 3,919	$3,184	$ -	$ 23,048	$ 53,524	$ 53,666	

Note: This analysis assumes 2.53% inflation rate, 4.53% discount rate, 4.04% vehicle finance rate, 3.42% electricity escalation rat
escalation rate.

4.1 *Simulation Results for Vehicle Traveling 12,330 Miles/Year*

An LCC analysis was performed on the 16 selected vehicles to determine the total vehicle ownership costs over 5-, 10-, and 15-year periods. Table 7 shows an example of the detailed LLC simulated results for a 2013 Nissan Leaf. The federal incentive is included in year 2 (2015) of the finance charges and purchased ownership cost columns. For a 10-year simulation, average and present values are shown at the bottom of the table, and the results only use the first 10 rows of data. Note that the battery replacement is at year 11.

Table 8 shows the results for all vehicles when costs described in the previous section and federal incentives are included in the analysis. The selected vehicles are listed in order of total annual costs from highest to lowest over the 10-year period.

Table 8. 10-Year LCC Simulation Results in Present Value Dollars ($)

Description	Fuel	Maintenance	Tires	Insurance	Electrical Energy	Taxes & License	Annual Cost
13 Tesla Model S BEV	0	4533	787	20638	4823	5393	9586
13 Ford E150 Van FFV	24685	9000	787	18861	0	3054	8414
13 Toyota Rav4 BEV	0	7833	787	21849	5948	4289	8208
13 Volkswagen Eos ICE	15974	7278	787	20122	0	3438	8172
13 Ford Cmax Energi PHEV	4313	7689	787	24929	2535	3409	7364
14 Honda Accord PHEV	4658	7556	767	19942	1375	3698	7331
13 Chevrolet Volt PHEV	228	5571	787	23234	4799	3812	7189
13 Honda Civic HEV	7620	7053	787	27780	0	2824	7001
13 Toyota Prius PHEV	4543	6500	787	22772	1501	3281	6863
13 Chevrolet Cruze Eco ICE	13459	7682	787	25429	0	2497	6836
13 Chevrolet Malibu Sdn ICE	12054	6994	787	23137	0	2699	6753
13 Hyundai Elantra Sdn ICE	10931	6723	787	24899	0	2511	6459
13 Toyota Prius HEV	6710	5878	787	21462	0	2865	6233
13 Chevrolet Spark ICE	11010	6909	787	26009	0	2291	6211
13 Nissan Leaf S BEV	0	5054	787	17532	3919	3184	5352
14 Chevrolet Spark BEV	0	7459	767	10031	3739	3009	4534

Note: Annual cost does not include salvage value at the end of the 10-year period

As expected, the high-cost vehicles with greater purchase price show greater LCCs than lower-purchased-price vehicles. It is also clear from the results that BEV vehicles are cost competitive with their ICE counterparts. In fact, two of the more popular BEV's show smaller LCCs than low-cost ICE conventional models. PHEV are also shown to be competitively priced compared to other ICE conventional vehicles. These results are similar to results shown by Alexander and Davis in an EPRI study [4] and are characteristic of the difference in operating fuel cost – a nominal 3:1 difference between ICE and BEV vehicles at today's fuel prices. The Nissan LEAF and Chevrolet Spark annual costs are $5,352 and $4,534, respectively (per 10-year period) while the conventional vehicles show annual costs of around $6,600. To present a graphical representation of the LCC costs and results, Figure 4 shows all of the vehicles studied.

Figure 4 shows the present values and annual costs for a 5-year ownership example. These results show the relative amounts of the various vehicle costs and show that the two least-cost vehicles are the Chevrolet Spark BEV and Nissan Leaf BEV. The Chevrolet Spark ICE is the third least-cost vehicle. Average annual costs are shown with and without salvage value at the end of year 5. Note here that the vehicles are ordered in the same manner as shown in Table 8, and the vehicles are no longer ordered from highest to lowest due to the change in simulation period and economics.

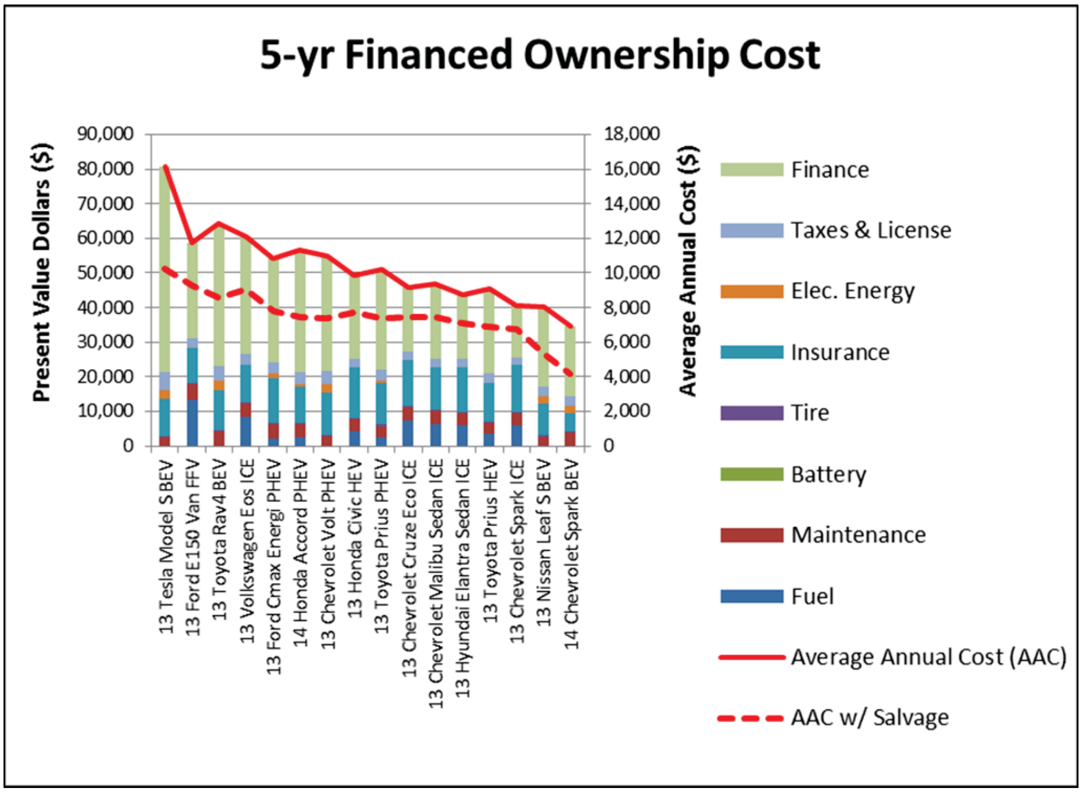

Figure 4. LCC 5-Year Simulation Results of Annual Costs/Year

The next set of results is presented in Table 9 where the annual costs are shown for a Leaf, Elantra, and Volt and for the cases where the ownership of the vehicle is held for 5, 10, or 15 years. Salvage values are included in these results.

Table 9. Average Annual Cost by Number of Simulation Years

Ownership Years	Average Annual Cost ($)		
	LEAF	Elantra	Volt
5	5,360	7,076	7,388
10	4,683	6,040	6,286
15	4,369	5,444	5,691

From the results shown in Table 9, again the Leaf EV is the least annual cost. The 15-year results also show the effect of battery replacement for both the Leaf and Volt. This result shows the relative difference where the Elantra is not affected due to battery replacement. Note that the results shown in Table 9 are valid when comparing a vehicle for a period of time, say five years, but not for comparing the same vehicle for 5 years or for 15 years since vehicle replacement may be required in the analysis.

4.2 Simulation Results for Vehicle Traveling 10,000, 20,000 and 30,000 Miles

One of the other factors evaluated by the LCC simulations was the effect of different miles per year traveled by the individual vehicle. For this case, runs of 10,000, 20,000, and 30,000 miles per year driven were made for the three vehicles – Leaf, Elantra, and Volt. These results are plotted in Figure 5, which shows average annual costs versus miles per year. The case for 12,330 miles is also noted in Figure 5.

From Figure 5, it can be observed that the curves are linear, except at the 10,000 to 12,000 mile range for the Nissan Leaf and Chevrolet Volt for the 10- and 15-year simulations. The nearly horizontal curve in this range is because the Leaf and Volt are entirely battery powered at this mileage range. Since the lines are linear, the effect of miles per year driven does not change the relative positions of the three vehicles. The annual costs are higher at higher mileage, which is as expected.

The equations are shown for the 10-year simulation to highlight the difference in efficiency between the all-electric Leaf, the PHEV Volt, and the Elantra ICE vehicles. The Leaf is more than twice as efficient as the other vehicles, given the assumptions used in this analysis.

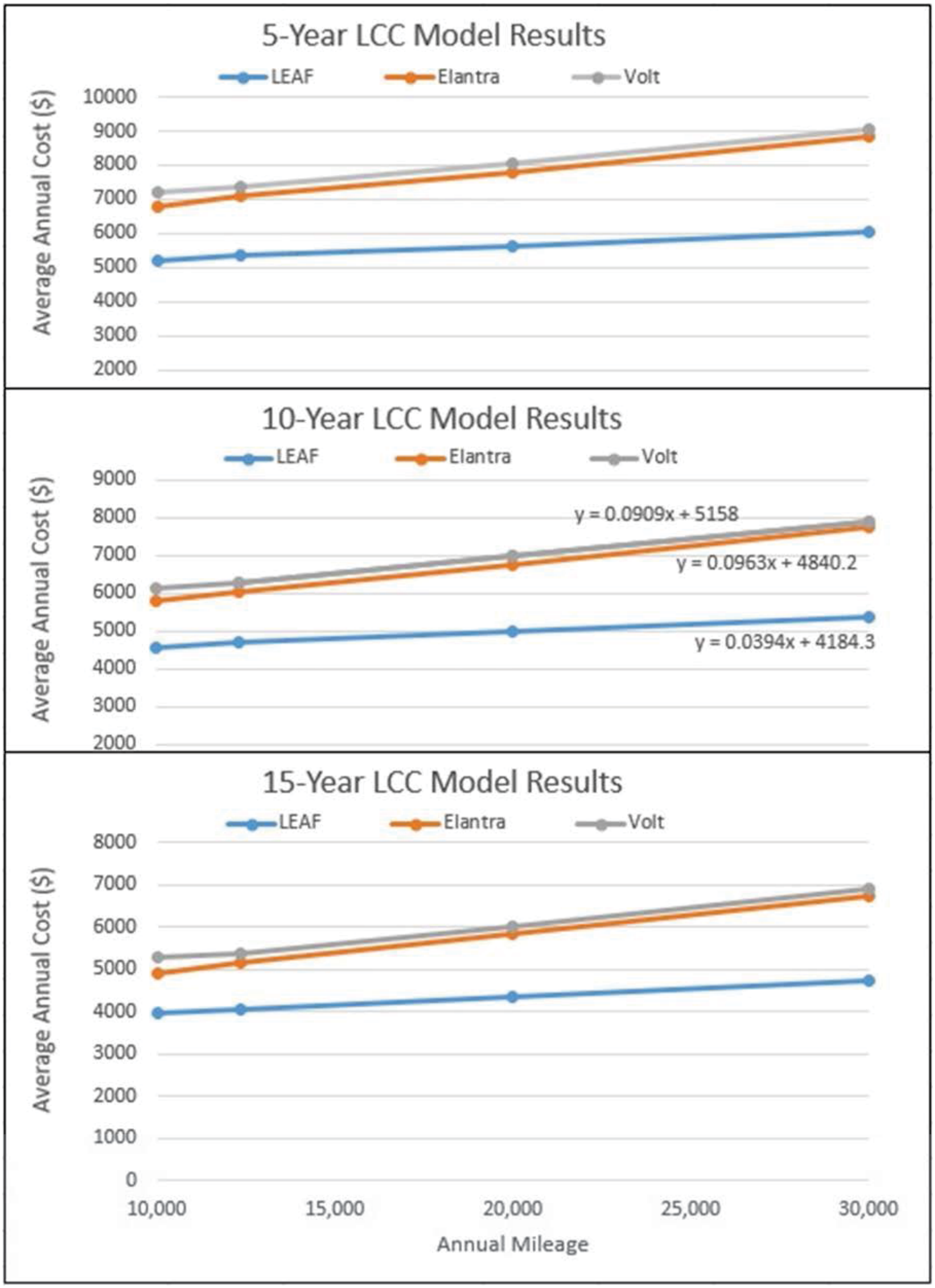

Figure 5. LCC Analysis for 5-, 10-, and 15-Year Ownership

4.3 Impact of Federal Incentives

Federal incentives are a mechanism to promote new technology into the mainstream. The incentives are primarily used to equalize costs within specific markets. However, they are also used to accelerate adoption and promote new technology. Calculations were made for the Leaf and Volt without federal incentives, and these calculations showed that the Leaf is still the least-cost vehicle compared to the Volt and Elantra at 5-, 10-, and 15-year ownerships. This result was similar to results shown in Figure 5.

4.4 Simulation Program Input Parameters and Example

This section of the report presents the LCC program input values and an example set of input values for three vehicles: the Nissan Leaf, the Hyundai Elantra, and the Chevrolet Volt. Table 10 presents these results – a list of all the program input parameters is in the left column and the values used are shown for each vehicle.

In Table 10, there are thirty values required to describe the vehicle and the economics. The output calculated values are shown in the last ten rows of the table.

4.5 Photovoltaics Provide Zero-Energy Transportation

One of the interesting issues concerning PEVs is the fact that the power need for an individual's car can be generated by photovoltaics (PV) (i.e., a PV system can completely eliminate the electric energy required to operate a PEV). If this PV system were grid-tied, the added flexibility allows the PV system to operate independently of when and where the vehicle is parked. The PV power required to offset PEV electrical energy use varies based on the efficiency of the EV motive system and the expected daily commute. For the vehicles studied in this report, a PV system of 0.88 to 3.6 kW would supply the needed electrical power if located in Florida, as shown in Figure 6. If this system was installed at a cost of $2,800/kW and assuming ¢11.42 per kWh, the PV would pay for itself in 16.4 years. PV electrical output degradation of 2%/year is included. Given that gasoline costs are nominally three times greater than electricity at today's prices, the payback for offsetting liquid fuel could be considered less than 6 years. Additionally, the PV system would eliminate all emissions resulting from the electrical motive energy. For BEV, and neglecting emissions from PV manufacturing, the vehicle would truly be a zero-emission vehicle.

Table 10. LCC Input Values and Vehicle Example Calculations

Vehicle:			
Year	**2013**	**2013**	**2013**
Make	Nissan	Hyundai	Chevrolet
Model	LEAF	Elantra	Volt
Type	BEV	ICE	PHEV
MSRP ($)	31,415	19,685	42,355
Range (miles)	75	--	38
Battery Size (kWh)	24	--	16.5
Battery Life (years)	12	--	12
Operating Cost:			
Regular Gasoline Cost ($/gal.)	3.206		
Premium Gasoline Cost ($/gal.)	3.648		
Electricity Cost ($/kWh)	0.1142		
Tire Cost ($)	450	450	450
Tire Mileage (miles)	50,000	50,000	50,000
Maintenance ($)	549	739	608
Insurance ($)	1,952	2,772	2,587
Federal Incentive ($)	7,500	--	7,500
Operating Efficiency:			
City MPG	--	28	35
Highway MPG	--	38	40
City kWh/mile	0.27	--	0.36
Highway kWh/mile	0.33	--	0.37
Driving Statistics:			
Local Miles:	33.9		
Local City Miles (%)	50		
Local Driving Days	118		
Commute Miles	34		
Commute City Miles (%)	75		
Commute Driving Days	245		
Economics:			
Inflation Rate (%)	2.53		
Discount Rate (%)	4.53		
Finance Rate (%)	3.25		
Electric Escalation Rate (%)	3.42		
Ethanol Escalation Rate (%)	1.7		
Gasoline Escalation Rate (%)	1.7		
Number of Years	5		
Calculation Output:			
Finance Cost ($)	23,048	18,743	33,464
Fuel Consumption ($)	0	5,840	0
Electric Consumption ($)	2,012	0	2,522
Maintenance Cost ($)	2,636	3,511	2,906
Tire Cost ($)	409	409	409
Insurance Cost ($)	9,167	13,018	12,148
Taxes & License ($)	2,934	2,260	3,562
Present Value w/o Salvage ($)	40,204	43,781	55,011
Present Value w/ Salvage ($)	26,800	35,380	36,940
Annual Operating Cost ($)	5,360	7,076	7,388

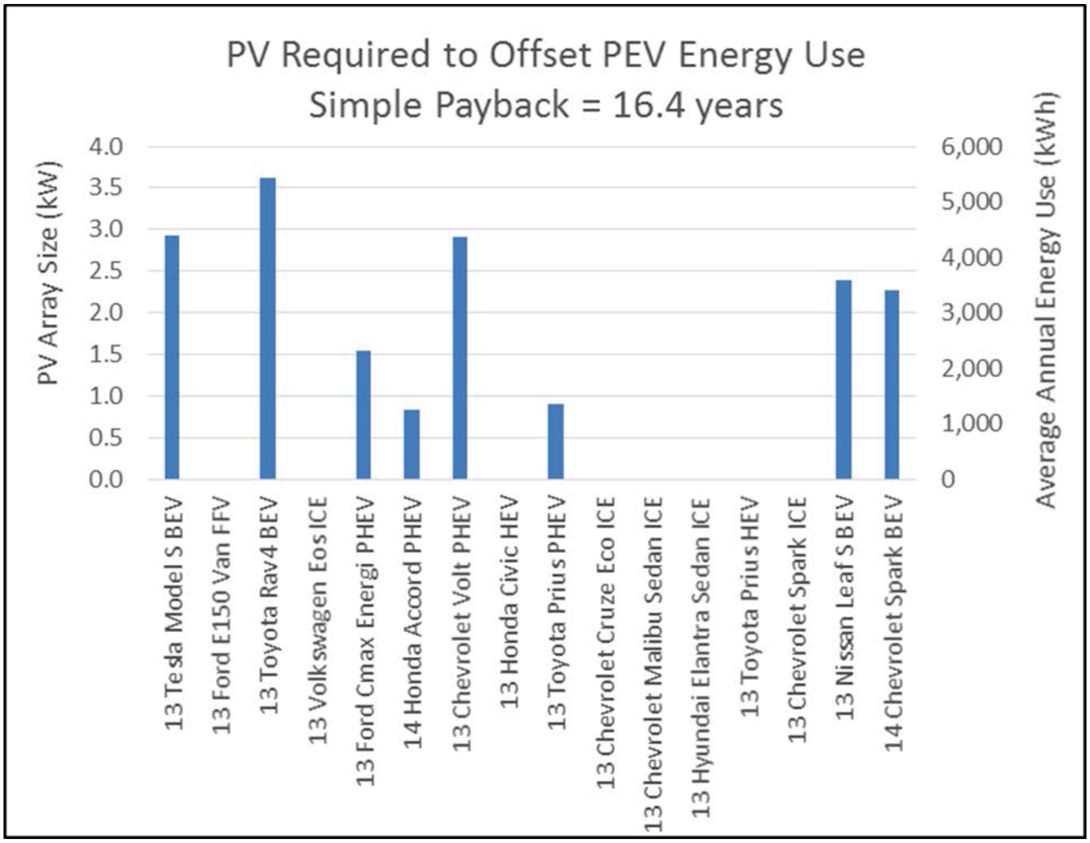

Figure 6. PV Array Sizes for PEV Zero-Emission Vehicles

IV. Conclusions

The major objective of this work was to develop an LCC model for automotive vehicles that accurately evaluates PEVs. The developed LCC model was used to compare ownership costs, on an annual basis, of PHEVs and BEVs to conventional ICE vehicles for an average number of miles driven per year. The analysis uses actual cost values for 16 production vehicles all sold in the United States.

The LCC model includes the vehicle costs of purchase price with federal incentives, if any; salvage value; fuel consumption (electricity and liquid fuel); tires; insurance, maintenance; state tax; and financed interest payments. The vehicles considered are hybrid, plug-in hybrid and battery-electric vehicles, as compared to ICEs using gasoline, ethanol, or diesel. It is noted that the traction battery replacement costs for PEVs are difficult to ascertain, yet they are included in the analysis by replacing the batteries in the 11th year to investigate the battery impact on overall costs. Economic factors used in the LCC include differing rates for inflation, discount, and fuel escalation and battery degradation in the PEVs to account for battery energy depletion over time. The LCC is performed over a 5-, 10-, or 15-year lifetime period.

For the specific case of 12,330 miles driven per year and for the selected economic factors, the LCC results show for all three lifetime cases that reasonably-priced, battery-powered vehicles are lower in annual cost than conventional ICE vehicles. The analysis was performed using the two lowest cost vehicles, a Nissan Leaf and a Hyundai Elantra. Comparing the other two most popular PEVs, the Chevrolet Volt and Toyota Prius, the results for both of these are higher annual costs than the Elantra.

The other result evaluated by the LCC simulations was the effect of different miles per year traveled by the individual vehicle. For this case, runs of 10,000, 20,000, and 30,000 miles per year driven were made for three vehicles – Leaf, Elantra, and Volt. These results showed that the effect of varying miles does not change the relative annual cost positions of the three vehicles. The annual costs are higher at higher mileage, which is as expected.

Calculations of annual cost were also made for the Leaf and Volt without federal incentives. These results showed that the Leaf is still least cost compared to the Elantra at 5-, 10-, and 15-year ownerships. The Volt is shown to have higher annual costs than either of these vehicles.

The other results presented were the inclusion of the LCC simulation program that can be downloaded and used by any individual with his or her own vehicle selection, miles driven and the application of PV power to determine the size of a PV array located in Florida that would completely power the electrical needs of a vehicle using a traction battery. The array size was determined to be 2.38 kW for the Nissan Leaf.

V. Acknowledgments

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APPENDIX A – PEVs Qualified for IRS Tax Credit (IRC-30D)

Manufacturer	Qualified Vehicle	Battery Capacity	Model Year	Credit Amount
American Honda Motor Co.	Accord Plug-In Hybrid	6.7	2014	$3,626
AMP Electric Vehicles, Inc.	AMP GCE Electric Vehicle		2012	$7,500
AMP Electric Vehicles, Inc.	AMP MLE Electric Vehicle		2012	$6,500
Azure Dynamics, Inc.	Azure Dynamics Transit Connect EV		2011/2012	$7,500
BMW of North America	BMW i3 Sedan with Ranger Extender	22	2014	$7,500
BMW of North America	BMW i3 Sedan	22	2014	$7,500
BMW of North America	BMW i8	7.1	2014	$3,793
Boulder Electric Vehicles, Inc.	Boulder Electric Delivery Van DV-500		2013	$7,500
Boulder Electric Vehicles, Inc.	Boulder Electric Shuttle DV500		2013	$7,500
Boulder Electric Vehicles, Inc.	Boulder Electric Flat Bed DV-500		2013	$7,500
Boulder Electric Vehicles, Inc.	Boulder Electric Service Body DV-500		2013	$7,500
BYD Motors, Inc.	BYD e6 Electric Vehicle		2012-2014	$7,500
Chrysler Group LLC	Fiat 500e	24	2013-2014	$7,500
CODA Automotive	CODA Sedan EV		2010/2012	$7,500
Electric Vehicles International	EVI-MD (Medium Duty) Electric truck		2011/2012	$7,500
Electric Vehicles International	EVI-WI (Walk-In) Electric truck		2011/2012	$7,500
Electric Mobil Cars	EMC Model E36 7 Passenger Wagon EV		2010	$7,500
Electric Mobil Cars	EMC Model E36t Pick-up Truck EV		2010	$7,500
Electric Mobil Cars	EMC Model E36v Utility Van EV		2010	$7,500
Fisker Automotive, Inc.	Fisker Karma Sedan		2012	$7,500
Ford Motor Company	Ford Focus Electric	23	2012-2014	$7,500
Ford Motor Company	Ford C-MAX Energi	7.6	2013-2014	$4,007
Ford Motor Company	Ford Fusion Energi	7.6	2013-2014	$4,007
General Motors Corporation	Cadillac ELR	16.5	2014	$7,500
General Motors Corporation	Chevrolet Volt	16.5	2011-2014	$7,500
General Motors Corporation	Chevrolet Spark EV	21	2014	$7,500
Mercedes-Benz	Mercedes-Benz Coupe/Cabrio EV	28	2013	$7,500
Mitsubishi Motors North America, Inc.	Mitsubishi i-MiEV	16	2012/2014	$7,500
Nissan North America	Nissan Leaf	24	2011-2014	$7,500
Porsche Cars North America, Inc.	Porsche 918 Spyder		2015	$3,667
Porsche Cars North America, Inc.	Porsche Panamera S E Hybrid	9.4	2014	$4,751.8
Smart USA Distributor, LLC	smart fortwo	17.6	2011	$7,500
Tesla Motors Inc.	Tesla Roadster	60/85	2008-2011	$7,500
Tesla Motors Inc.	Tesla Model S	60/85	2012-2014	$7,500
Think NA	Think City EV		2011	$7,500
Toyota Motor Sales, S.S.A., Inc.	Toyota Prius PHEV	4.4	2012-2014	$2,500
Toyota Motor Sales, S.S.A., Inc.	Toyota RAV4 EV	41.8	2012-2014	$7,500
VIA Motors, Inc.	VIA 2500 ER Electric Passenger Van		2014	$7,500
VIA Motors, Inc.	VIA 1500 ER Electric Truck 4WD		2014	$7,500
VIA Motors, Inc.	VIA 2500 ER Electric Cargo Van		2014	$7,500
VIA Motors, Inc.	VIA 1500 ER Electric Truck 2WD		2014	$7,500
Wheego Electric Cars, Inc.	Wheego LiFe EV		2011	$7,500
Zenith Motors	Zenith Electric Van		2014	$7,500

APPENDIX B – Calculating Annual Fuel Based Mileage

The following equations are used to calculate the mileage shown in Table 3. The italicized variables are found in Table 3 or are a result of the PHEV calculations when daily local or commute travel exceeds the battery range, and the *DailyLocalMilesGas* or *DailyCommuteMilesGas* represents the gas miles traveled without regards to battery degradation. See example Table 4 for PHEV Gas Miles Traveled for year 1 (e.g., 3.9 and 4 local and commute gas miles traveled, respectively).

Gas City Mileage:

GasCityMiles = 0 — BEV

GasCityMiles = Local City + Commute City — ICE, HEV

$$\mathit{GasCityMiles} = \frac{\mathit{MPGc}\ (\mathit{Local\ City} + \mathit{Commute\ City})\ (1 - \mathit{Local}\ \%\ \mathit{Flex\ Driving})}{((1 - \mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGc}) + (\mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGFFc}))} \qquad \text{FFV}$$

GasCityMiles = DailyLocalMilesGas (Local Days) (Local Percent City) + DailyCommuteMilesGas (Commute Days) (Commute Percent City) — PHEV

Gas Highway Mileage:

GasHighwayMiles = 0 — BEV

GasHighwayMiles = Local Highway +Commute Highway — ICE, HEV

$$\mathit{GasHighwayMiles} = \frac{\mathit{MPGh}\ (\mathit{Local\ Highway} + \mathit{Commute\ Highway})}{\mathit{MPGh} + \mathit{MPGFFh}} \qquad \text{FFV}$$

GasHighwayMiles = DailyLocalMilesGas (Local Days) (1-Local Percent City) + DailyCommuteMilesGas (Commute Days) (1-Commute Percent City) — PHEV

Electric City Mileage:

ElectricCityMiles = Local City +Commute City — BEV

ElectricCityMiles = 0 — ICE, HEV, FFV

ElectricCityMiles = DailyLocalMilesElectric (Local Days) (Local Percent City) + DailyCommuteMilesElectric (Commute Days) (Commute Percent City) — PHEV

Electric Highway Mileage:

ElectricHighwayMiles = Local Highway +Commute Highway — BEV

ElectricHighwayMiles = 0 — ICE, HEV, FFV

ElectricHighwayMiles = DailyLocalMilesElectric (Local Days) (1-Local Percent City) + DailyCommuteMilesElectric (Commute Days) (1-Commute Percent City) — PHEV

Flex City Mileage:

FlexCityMiles = 0 — BEV, ICE, HEV, PHEV

$$\mathit{FlexCityMiles} = \frac{\mathit{MPGFFc}\ (\mathit{Local\ City} + \mathit{Commute\ City})\ (\mathit{Local}\ \%\ \mathit{Flex})}{((1 - \mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGc}) + (\mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGFFc}))} \qquad \text{FFV}$$

Flex Highway Mileage:

FlexHighwayMiles = 0 — BEV, ICE, HEV, PHEV

$$\mathit{FlexHighwayMiles} = \frac{(\mathit{MPGFFh}\ (\mathit{Local\ Highway} + \mathit{Commute\ Highway})\ (\mathit{Commute}\ \%\ \mathit{Flex}))}{((1 - \mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGh}) + (\mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGFFh}))} \qquad \text{FFV}$$

APPENDIX C – Calculating Electric, Gas, or Flex Fuel Consumption

As a check, the fuel use associated with local and commute driving shown in Table 4 were calculated. These calculations are somewhat more involved and are shown here in equation form. The italicized variables are found in Table 3 or are a result of the PHEV calculations when daily local or commute travel exceeds the battery range, and the *DailyLocalMilesGas* or *DailyCommuteMilesGas* represents the gas miles traveled without regards to battery degradation. See example Table 4 for PHEV Gas Miles Traveled for year 1 (e.g., 3.9 and 4 local and commute gas miles traveled, respectively).

$$\mathit{LocalUseGas} = 0 \qquad \text{BEV}$$

$$\mathit{LocalUseGas} = \mathit{Local\ City} / \mathit{MPGc} + \mathit{Local\ Highway} / \mathit{MPGh} \qquad \text{ICE, HEV}$$

$$\mathit{LocalUseGas} = \mathit{DailyLocalMilesGas}\ (\mathit{Local\ Days})\ (\mathit{Local\ Percent\ City} / \mathit{MPGc} \qquad \text{PHEV}$$
$$\mathit{DailyLocalMilesGas}\ (\mathit{Local\ Days})\ (1\text{-}\mathit{Local\ Percent\ City})/\mathit{MPGh}$$

$$\mathit{LocalUseGas} = \frac{(\mathit{Local\ City})\ (1\text{-}\mathit{Local}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGc}) + (\mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGFFc}))} + \qquad \text{FFV}$$
$$\frac{(\mathit{Local\ Highway})\ (1\text{-}\mathit{Commute}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGh}) + (\mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGFFh}))}$$

$$\mathit{CommuteUseGas} = 0 \qquad \text{BEV}$$

$$\mathit{CommuteUseGas} = \mathit{Commute\ City} / \mathit{MPGc} + \mathit{Commute\ Highway} / \mathit{MPGh} \qquad \text{ICE, HEV}$$

$$\mathit{CommuteUseGas} = \mathit{DailyCommuteMilesGas}\ (\mathit{Commute\ Days})\ (\mathit{Commute\ Percent\ City}) / \mathit{MPGc} + \qquad \text{PHEV}$$
$$\mathit{DailyCommuteMilesGas}\ (\mathit{Commute\ Days})\ (1\text{-}\mathit{Commute\ Percent\ City})/\mathit{MPGh}$$

$$\mathit{CommuteUseGas} = \frac{(\mathit{Commute\ City})\ (1\text{-}\mathit{Local}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGc}) + (\mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGFFc}))} + \qquad \text{FFV}$$
$$\frac{(\mathit{Commute\ Highway})\ (1\text{-}\mathit{Commute}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGh}) + (\mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGFFh}))}$$

$$\mathit{LocalUseFlex} = 0 \qquad \text{BEV, ICE, HEV, PHEV}$$

$$\mathit{LocalUseFlex} = \frac{(\mathit{Local\ City})\ (\mathit{Local}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGc}) + (\mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGFFc}))} + \qquad \text{FFV}$$
$$\frac{(\mathit{Local\ Highway})\ (1\text{-}\ \mathit{Local}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGh}) + (\mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGFFh}))}$$

$$\mathit{CommuteUseFlex} = 0 \qquad \text{BEV, ICE, HEV, PHEV}$$

$$\mathit{CommuteUseFlex} = \frac{(\mathit{Commute\ City})\ (\mathit{Local}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGc}) + (\mathit{Local}\ \%\ \mathit{Flex})\ (\mathit{MPGFFc}))} + \qquad \text{FFV}$$
$$\frac{(\mathit{Commute\ Highway})\ (\mathit{Commute}\ \%\ \mathit{Flex})}{((1\text{-}\ \mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGh}) + (\mathit{Commute}\ \%\ \mathit{Flex})\ (\mathit{MPGFFh}))}$$

$$\mathit{LocalUseElec} = 0 \qquad \text{FFV, ICE, HEV}$$
$$\mathit{LocalUseElec} = \mathit{Minimum\ of}\ (\mathit{Local\ Miles},\ \mathit{Battery\ Range}) \qquad \text{PHEV, BEV}$$

$$\mathit{CommuteUseElec} = 0 \qquad \text{FFV, ICE, HEV}$$
$$\mathit{CommuteUseElec} = \mathit{Minimum\ of}\ (\mathit{Commute\ Miles},\ \mathit{Battery\ Range}) \qquad \text{PHEV, BEV}$$

APPENDIX D – Edmunds.com True Cost to Own Results

Insurance, Depreciation, Maintenance, and Repairs

The values for these vehicle costs were taken for the city of Orlando, Florida. Analysis for one example, the Nissan Leaf, follows. Total cash price shown is representative of vehicles purchased in the Orlando, Florida area and was used to calculate the vehicle depreciation rate for the first 5 years of ownership. Insurance was calculated as the average annual value over the 5-year period. Annual maintenance is the sum of the maintenance and repair data averaged over the 5-year period less the cost of tires. Information for other vehicles may be obtained in Reference [5].

True Cost to Own®		http://www.edmunds.com/tco.html					
Nissan Leaf		$30,473	Total Cash	Price		Orlando	$32,816
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**5 Yr. Total**	**Average**
Insurance	$1,820	$1,884	$1,950	$2,018	$2,088	$9,760	$1,952
Depreciation	$6,515	$2,881	$2,535	$2,248	$2,017	$16,196	
Maintenance	$204	$389	$269	$667	$1,003	$2,532	$639.4
Repairs	$0	$0	$96	$232	$337	$665	
Tax Credit	($7,500)					($7,500)	
True Cost to Own	**$4,670**	**$6,557**	**$6,042**	**$6,139**	**$6,190**	**$29,598**	