Methodology for Calculating Cost per Mile for Current and Future Vehicle Powertrain Technologies, with Projections to 2024

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M. Ruth
National Renewable Energy Laboratory

T.A. Timbario, T.J.Timbario, and M. Laffen
Alliance Technical Services, Inc.

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Methodology for Calculating Cost-per-Mile for Current and Future Vehicle Powertrain Technologies, with Projections to 2024

Mark Ruth
National Renewable Energy Laboratory

Thomas A. Timbario, Thomas J. Timbario, Melissa Laffen
Alliance Technical Services, Inc.

ABSTRACT

Currently, several cost-per-mile calculators exist that can provide estimates of acquisition and operating costs for consumers and fleets. However, these calculators are limited in their ability to determine the difference in cost per mile for consumer versus fleet ownership, to calculate the costs beyond one ownership period, to show the sensitivity of the cost per mile to the annual vehicle miles traveled (VMT), and to estimate future increases in operating and ownership costs. Oftentimes, these tools apply a constant percentage increase over the time period of vehicle operation, or in some cases, no increase in direct costs at all over time. A more accurate cost-per-mile calculator has been developed that allows the user to analyze these costs for both consumers and fleets. Operating costs included in the calculation tool include fuel, maintenance, tires, and repairs; ownership costs include insurance, registration, taxes and fees, depreciation, financing, and tax credits. The calculator was developed to allow simultaneous comparisons of conventional light-duty internal combustion engine (ICE) vehicles, mild and full hybrid electric vehicles (HEVs), and fuel cell vehicles (FCVs). Additionally, multiple periods of operation, as well as three different annual VMT values for both the consumer case and fleets can be investigated to the year 2024. These capabilities were included since today's "cost to own" calculators typically include the ability to evaluate only one VMT value and are limited to current model year vehicles. The calculator allows the user to select between default values or user-defined values for certain inputs including fuel cost, vehicle fuel economy, manufacturer's suggested retail price (MSRP) or invoice price, depreciation and financing rates.

INTRODUCTION

As advanced vehicle technology development programs are undertaken, it is useful to have an understanding of the ownership and operating costs. Advanced ICE technologies and hybrid propulsion systems have been in the market for a few years, to the point where acquisition and operating costs can be identified with a high degree of accuracy. For several years, the U.S. Department of Energy (DOE) and other global government agencies have sponsored the development of FCV propulsion systems. A number of worldwide automotive manufacturers are developing FCV systems with the expectation that limited production quantities will be offered in the 2013-2015 timeframe. Having a calculation tool that can assess the various elements of vehicle acquisition and operating costs and compare them among competing technologies is useful to identify those cost elements that contribute the most (or least) to cost competitiveness and provide insight on where further development efforts can be applied to achieve greater cost competitiveness.

This paper is a summary of the development by the authors of a more accurate cost-per-mile calculator that allows the user to analyze vehicle acquisition and operating costs for both consumers and fleets. Two scenarios were chosen for this study: one defines a mature, market-ready FCV technology and hydrogen fueling infrastructure in 2010; the other examines a "market introduction" case with FCVs as an emerging technology in the 2013-2015 timeframe with an immature hydrogen fueling infrastructure. Cost-per-mile results are reported only for consumer-operated vehicles travelling 15,000 miles per year and for fleet vehicles travelling 25,000 miles per year.

METHODOLGY FOR CALCULATING FUTURE VEHICLE ATTRIBUTES

CONVENTIONAL ICE VEHICLE

Original equipment manufacturer (OEM) data beginning with model year 1993 (when available) were obtained for six mid-size class sedans[1]: the Chevrolet Malibu, Ford Fusion, Honda Accord, Nissan Altima, Saturn Aura, and Toyota Camry. These vehicles were specifically chosen because each has or had a hybrid electric variant. In addition, manufacturer's data for the Ford Taurus (which was discontinued in 2006 and subsequently reintroduced in 2008) were also collected to help fill in early 1990s data because vehicles like the Fusion and Aura are both relatively new models. Selected vehicle attributes, i.e., fuel economy, exterior dimensions and interior volumes, weight, performance, and pricing (MSRP and invoice), were collected for each of the seven models through model year 2010 [1]. Vehicle design refresh cycles for each model were also analyzed. The available data suggest that OEMs update their individual vehicle models approximately every five years (or one vehicle generation). Therefore, starting with 2010, a vehicle will likely be refreshed in 2015, 2020, 2025, and so on. While researching vehicle attributes for the chosen vehicle models, care was taken to determine if the vehicle class changed during the course of the refresh cycle; when an updated model fell outside of the mid-size class, the data for those attributes were disregarded. For example, the newest generation of the Honda Accord is classified as a large car although the Accord was classified as a mid-size vehicle between 1998 and 2007. Therefore, Honda Accord data for model years 2008-2010 and prior to 1998 were not included in determining future vehicle attributes.

The vehicle attributes mentioned above were averaged together for each model year. For example, wheelbase data for a 2002 Chevrolet Malibu, Honda Accord, Nissan Altima and Toyota Camry were averaged together to get a generic 2002 mid-size sedan wheelbase. Again, not all seven models were used in the averaging due to class change or vehicle model availability in that model year. The process was repeated for each vehicle attribute for model years 1993-2010. The resulting averaged attributes were used to define a generic mid-size conventional ICE vehicle for each model year. Model years with similar attributes were grouped together, forming the generic mid-size conventional ICE vehicle generations. Since 1993, this generic mid-size vehicle has gone through four generations with the attributes listed in Table 1.

Table 1 – Generic Conventional ICE Mid-Size Sedan Past and Current Attributes

GENERATION	1	2	3	4
MODEL YEAR	1993-1996	1997-2001	2002-2007	2008-2010
Fuel Economy (mpg)				
City	18	19	20	22
Highway	26	27	29	31
Combined	21	22	24	25
Range[a] (mi)				
City	315	316	363	387
Highway	457	455	516	544
Combined	365	369	420	447
Dimensions & Capacities				
Length (in)	190.6	191.1	190.0	190.4
Width (in)	70.6	70.6	70.7	71.1
Wheelbase (in)	104.9	106.8	108.0	109.9
Curb weight (lb)	3052	3070	3124	3307
Luggage (ft^3)	16.2	15.3	15.5	15.3
Fuel tank (gal)	17.5	16.7	17.7	17.7
Performance				
Horsepower	134	144	162	168
Acceleration, 0-60 mph (sec)	N/A	N/A	8.4	7.9
Drag coefficient	N/A	0.30	0.30	0.32
Power-to-weight	0.0440	0.0467	0.0520	0.0508
Pricing (nominal$)				
MSRP	N/A	$16,641	$17,623	$19,926
Invoice	N/A	$15,047	$16,338	$18,748

[a]Range is calculated by multiplying fuel economy by fuel tank volume; N/A - not available

[1] Mid-size is defined as interior volume greater than or equal to 110 cubic feet but less than 120 cubic feet (Code of Federal Regulations, Title 40, Section 600.315-08, *Classes of comparable automobiles)*.

Generally, the generic conventional ICE mid-size sedan has grown in size and weight through each generation while becoming more fuel efficient with increasing horsepower.

Two methods were utilized to forecast the generic conventional ICE vehicle's 2015 and 2020 attributes (generations 5 and 6). Method 1 employs the same technique that was used to group the generic mid-size sedan's attributes. OEM data for each model year (1993-2010) for the Chevrolet Malibu were grouped together to form vehicle generations. The process was repeated for the Fusion, Altima, and Camry. (Data for the Taurus and Accord were not utilized for this method because the Taurus was discontinued in 2006 and the Accord is now classified as a large car). This method could not be applied to the Aura since it has been available for only one generation. Each individual generational attribute was plotted with a best fit curve for each vehicle, and the curve was used to project the value of that attribute for the next two vehicle generations. The projected 2015 (generation 5) attributes for the four vehicles were averaged together in a similar fashion as for each of the generation 1, 2, 3 and 4 attributes in Table 1; the process was repeated for 2020 (generation 6). It should be noted that this process was not applied for vehicle pricing. Both MSRP and invoice price, which were provided in current dollars for 1993-2010, were converted to 2009 constant dollars using the Consumer Price Index for All Urban Consumers (CPI-U) for New Cars [2]. MSRP and invoice were plotted in 2009 constant dollars and projected using a best fit curve to obtain future vehicle pricing.

Method 2 also uses a best fit curve projection to determine generation 5 and 6 attributes. However, the data used in the projection are that of the generic mid-size vehicle generations as seen in Table 1. MSRP and invoice pricing were forecasted using the same process as was used in Method 1. Both methods yielded very similar results (see Table 2). Method 1 and Method 2 were then averaged together, yielding the final 2015 and 2020 conventional ICE vehicle attributes used as default assumptions in the calculation tool. Again, the general trend is increasing vehicle size and weight with higher fuel efficiency and horsepower.

Table 2 – Generic Conventional ICE Vehicle Future Attributes

GENERATION	5		6	
MODEL YEAR	2015		2020	
METHOD	1	2	1	2
Fuel Economy (mpg)				
City	24	24	25	25
Highway	33	33	35	35
Combined	27	27	28	29
Range (mi)				
City	421	419	448	457
Highway	585	581	617	623
Combined	478	479	503	514
Dimensions & Capacities				
Length (in)	191.0	190.1	192.1	190.0
Width (in)	71.8	71.7	72.5	72.6
Wheelbase (in)	109.8	110.3	110.5	110.9
Curb weight (lb)	3371	3345	3482	3432
Luggage (ft^3)	15.7	15.8	15.8	16.5
Fuel tank (gal)	17.8	17.8	17.7	18.0
Performance				
Horsepower	187	185	208	200
Power-to-weight	0.0555	0.0553	0.0598	0.0583
Pricing (2009$)				
MSRP	$22,346	$21,891	$24,788	$24,044
Invoice	$21,198	$21,076	$23,672	$23,591

The 2015 and 2020 future attributes were compared to those identified in existing literature. Several sources [3-16] were identified that projected future fuel economy of conventional ICE vehicles as well as some other vehicle attributes, namely range, curb weight, engine horsepower, power-to-weight ratio, and MSRP. The projections in several of these references reflect expectations that advanced technologies will be implemented in the vehicle fleet and are expressed as a percent increase over current vehicle fuel economy. Examples of future technologies include:

- Drag reduction
- Low rolling resistance tires
- Variable compression ratio
- Camless valve actuation

- Lean burn gasoline direct injection
- Gasoline homogeneous charge compression ignition dual mode
- Low friction lubricants
- Engine friction reduction
- Advanced continuously variable transmission

Fuel economy forecasts from the present study, as described above, were compared to fuel economy projections in the references. The forecasts in the cited sources were averaged together for each attribute and compared to the forecasts from this study. A comparison between the two methods was generally favorable (see Table 3).

Table 3 – Comparison of Projected Conventional ICE Attributes

GENERATION	5		6	
MODEL YEAR	2015		2020	
SOURCE	This Study	Ref[b]	This Study	Ref[b]
Fuel Economy (mpg)				
City	24	24	25	27
Highway	33	33	35	37
Combined	27	29	28	31
Range (mi)				
Highway	583	598	620	634
Dimensions & Capacities				
Curb weight (lbs)	3358	3254	3457	3222
Performance				
Horsepower	186	166	204	167
Power-to-weight	0.0554	0.0502	0.0591	0.0474
Pricing (2009$)				
MSRP	$22,119	$21,978	$24,416	$24,538

[b]References [3-16]

HYBRID ELECTRIC VEHICLES

The authors examined two different HEV powertrains: mild and full. A mild HEV can be defined as basically a conventional ICE vehicle with a motor/generator that allows for engine shut-down in various situations, i.e. braking, coasting, etc. Mild HEVs do not posses an independent hybrid drivetrain, like the full HEV, and therefore cannot run solely on the electric motor. When compared to full HEVs, mild HEVs have relatively small electric motors, small battery capacity, and small increases in fuel economy. However, both mild and full HEVs typically employ regenerative braking and engine assist.

Mild HEVs

OEM data for 2005-2010 conventional and hybrid electric versions of the Chevrolet Malibu, Ford Fusion, Honda Accord, Nissan Altima, Saturn Aura and Toyota Camry were compiled [1]. As was done with the conventional ICE vehicles, attributes of each HEV were averaged together to determine generic HEV attributes for each model year. Once the averaging process was complete, the model years with similar attributes were grouped together to form vehicle generations. It was determined that one mild HEV generation has existed. Neither Method 1 nor Method 2, which was used for the conventional ICE vehicle, could be used to project future mild HEV attributes due to the lack of historical generational data. Instead, a new method was utilized that compared the attributes of each mild HEV (i.e., increases in fuel economy, curb weight, etc.) with those of its conventional ICE counterpart. The differences in each attribute, including MSRP and invoice pricing, were then forecasted using a best fit curve to project the 2015 (generation 2) and 2020 (generation 3) mild HEV attributes. For MSRP and invoice pricing, these results were used as a check against prices projected using the same methodology that was used in Method 2 for the conventional ICE vehicle. The forecasted mild HEV attributes were compared to projections from literature sources. Several sources [7,10,13,17,18] that provided projections of HEV attributes were identified; the projections were averaged together and used to verify the results of the best fit curve projections. The comparison between the future mild HEV attributes projected as described above and those of the referenced sources can be seen in Table 4.

Table 4 – Comparison of Projected Mild HEV Attributes

GENERATION	2		3	
MODEL YEAR	2015		2020	
SOURCE	This Study	Ref[c]	This Study	Ref[c]
Fuel Economy (mpg)				
City	41	40	50	42
Highway	33	34	35	36
Combined	38	42	42	48
Range (mi)				
Highway	721	711	855	775
Dimensions & Capacities				
Curb Weight (lb)	3473	3391	3530	3491
Performance				
Horsepower	156	133	158	146
Power-to-weight	0.0448	0.0391	0.0448	0.0417
Pricing (2009$)				
MSRP	$30,426	$26,190	$34,176	$31,042

[c]References [7,10,13,17,18]

Full HEV

The only commercially available mid-size class full HEV is the Toyota Prius, now in its third generation. OEM data beginning with the Prius's introduction in the United States in 2001 were obtained [1]. Method 1, as explained in the Conventional ICE Vehicle section above, was utilized to determine the future full HEV attributes. These future attributes were compared to the average attributes of the references [4,5,7,8,13,14,18-20] from a literature survey. The comparison can be seen in Table 5.

Table 5 – Comparison of Projected Full HEV Attributes

GENERATION	4		5	
MODEL YEAR	2015		2020	
SOURCE	Authors	Ref[d]	Authors	Ref[d]
Fuel Economy (mpg)				
City	54	50	55	52
Highway	50	N/A	51	N/A
Combined	52	54	54	59
Range (mi)				
Highway	637	767	660	837
Dimensions & Capacities				
Curb weight (lb)	3183	3169	3322	3206
Performance				
Horsepower	113	118	133	129
Power-to-weight	0.0354	0.0355	0.0401	0.0378
Pricing (2009$)				
MSRP	$26,755	$27,269	$29,947	$28,369

[d]References [4,5,7,8,13,14,18-20]

FUEL CELL VEHICLE

Currently, there is only one commercial mid-size FCV, the Honda FCX Clarity. Although available to the public, this limited production vehicle is for lease only in three California markets (Torrance, Santa Monica and Irvine), with no option to buy. The $600 per month, three-year lease covers maintenance costs and collision insurance [21]. Although a limited production vehicle, the FCX Clarity provides a good baseline for mid-size FCV attributes and represents the first generation of FCVs for this study. Since no historical information exists for mid-size FCVs, published studies and DOE goals/targets were used to envision what the next two generations of FCV attributes may be.

The authors examined two FCV scenarios. The Target FCV Scenario assumes the FCV is a mature technology in 2010, fully competitive with conventional ICE vehicles and HEVs and manufactured in production volumes similar to today's rates, achieving all

DOE cost goals/targets; the Current FCV Scenario looks at a "market introduction" case with FCVs as an emerging technology entering the market in 2013 and using today's cost estimates for its subsystems.

To determine MSRP in the Target FCV Scenario, the FCV subsystem costs were calculated relative to a conventional ICE vehicle. Cost estimates and DOE cost goals were taken from Plotkin et al. [14]. Table 6 and Table 7 list those subsystem components and accompanying costs for the FCV and conventional ICE vehicle. Intermediate costs for years not provided in Tables 6 and 7 were obtained by plotting each subsystem with a best fit curve. Fuel cell size and hydrogen storage potential were assumed to be the same as the Honda FCX Clarity, 100 kW and 3.92 kg H_2 at 350 bar, respectively. The conventional ICE vehicle subsystem costs were then subtracted from the FCV subsystem costs to obtain the incremental subsystem costs of the FCV. As outlined in Plotkin et al. [14], the costs in Tables 6 and 7 are manufacturing costs and are not representative of MSRP. Therefore, Plotkin et al. [14] multiplied these manufacturing costs by 1.5 to obtain the retail price equivalent (RPE). The incremental RPE of the FCV over the conventional ICE vehicle was obtained by summing the incremental subsystem costs and multiplying by 1.5. This increment was then added to the conventional ICE vehicle MSRP to obtain the FCV MSRP (see Table 8). The historical percent difference between MSRP and invoice was compared for the vehicles outlined in the Conventional ICE Vehicle section. Analysis determined that the difference is slowly decreasing with each vehicle generation, with the invoice price being 95% of MSRP for the 2015 model year and 96% of MSRP in 2020. FCV invoice pricing was calculated using these percentages of MSRP.

The Current FCV Scenario uses the current manufacturing cost estimates listed in Plotkin et al. [14] to determine FCV MSRP (see Table 9). A similar analysis to that of the Target FCV Scenario was utilized: the difference in subsystem costs between the FCV and conventional ICE vehicle was determined. The incremental cost of the FCV was multiplied by 1.5, as used in Plotkin et al. [14] to obtain the RPE and then added to the conventional ICE vehicle MSRP for 2013. The subsequent years then follow the same declining MSRP trend as is used in the Annual Energy Outlook [5]. The resulting MSRP agrees favorably with comments by manufacturers about future FCVs. Toyota expects to price its FCV at $50,000 in 2015; Hyundai-Kia is confident that its price will be lower [22].

Table 6 – FCV Subsystem Costs (2009$)

SCENARIO	Target			Current
YEAR	2010	2015	2020	2010
Fuel cell system	$4,500	$4,500	$3,833	$10,800
Hydrogen storage	$521	$263	$263	$1,956
Motor	$1,110	$700	$574	$1,300
Battery	$1,000	$1,000	$910	$2,400
Transmission	$100	$100	$100	$100
Electronics	$790	$500	$22	$1,200
Exhaust	$0	$0	$0	$0

Table 7 – Conventional ICE Subsystem Costs (2009$)

YEAR	2010	2015	2020
Engine	$1,700	$1,805	$1,882
Hydrogen storage	$0	$0	$0
Motor	$0	$0	$0
Battery	$0	$0	$0
Transmission	$100	$100	$0
Electronics	$0	$0	$0
Exhaust	$400	$400	$400

After a review of literature [14,21,23-25], it was determined that the only other vehicle attribute that could be projected over the next two generations of FCVs is fuel economy. The average of the projections in the literature is provided in Tables 8 and 9.

Table 8 – Current and Projected FCV Attributes, Target FCV Scenario

SOURCE	Ref [21]	Ref[e]	Ref[e]
GENERATION	1	2	3
MODEL YEAR	2010	2015	2020
Fuel Economy (mpg)			
City	60	68	73
Highway	60	68	73
Combined	60	68	73

Range (mi)	240	N/A	N/A
Dimensions & Capacities Length (in) Width (in) Wheelbase (in) Curb weight (lb) Luggage (ft^3) Fuel tank (kg)	 190.3 72.7 110.2 3582 13.1 3.92 @ 350 bar	 N/A N/A N/A N/A N/A N/A	 N/A N/A N/A N/A N/A N/A
Performance Fuel cell (kW)	 100	 N/A	 N/A
Pricing (2009$) MSRP	 $28,917	 $30,107	 $32,992

[e]References [14,23-25]

Table 9 – Current and Projected FCV Attributes, Current FCV Scenario

SOURCE	N/A	Ref [21]	Ref[f]
GENERATION	N/A	1	2
MODEL YEAR	2010	2015	2020
Fuel Economy (mpg) City Highway Combined	 N/A N/A N/A	 60 60 60	 68 68 68
Range (mi)	N/A	240	N/A
Dimensions & Capacities Length (in) Width (in) Wheelbase (in) Curb weight (lb) Luggage (ft^3) Fuel tank (kg)	 N/A N/A N/A N/A N/A N/A	 190.3 72.7 110.2 3582 13.1 3.92 @ 350 bar	 N/A N/A N/A N/A N/A N/A
Performance Fuel cell (kW)	 N/A	 100	 N/A
Pricing (2009$) MSRP	 N/A	 $43,280	 $40,801

[f]References [14,23-25]

DIRECT COSTS

OPERATING COSTS

Gasoline

Four gasoline price projection data sets from the Energy Information Administration are included in the cost-per-mile calculation tool. Two are from the Annual Energy Outlook 2009 [11,26]: the high price case (default for the tool for both the Target FCV Scenario and the Current FCV Scenario) and the updated reference case, both converted to 2009 dollars. The third and fourth are from the Annual Energy Outlook 2010 [19,27] which includes a high oil price case and a reference case, both of which are also converted to 2009 dollars. Fuel costs were calculated as follows:

$$\text{Fuel Cost}_{20XX} = \text{Fuel Price}_{20XX} \times \text{VMT} \div \text{MPG}_y \qquad (1)$$

where 20XX denotes the year, VMT is vehicle miles traveled, mpg is the EPA adjusted combined fuel economy in miles per gallon gasoline equivalent and Y is the vehicle generation.

Hydrogen

Future hydrogen prices were determined using projections from the study Transitions to Alternative Transportation: A Focus on Hydrogen [23]. The hydrogen price projections (in dollars per gasoline gallon equivalent) to the year 2050 from the hydrogen success case (Case 1) were used as illustrated in Figure 1. The historical CPI-U [28] was used to convert the hydrogen prices to 2009 dollars and the fuel cost for each specific year was generated from Equation 1. Just as the Target FCV Scenario assumes a fully mature FCV technology, so does it assume a fully integrated hydrogen fueling station infrastructure. Therefore, the starting point on the hydrogen price curve presented in the study was shifted to that of 2019 to represent a lower hydrogen cost in 2010 for the Target FCV Scenario ($3.85 in 2009$). In effect, the 2019 price becomes the 2010 price, the 2020 price becomes the 2011 price, and so on for the out years in the Target FCV Scenario. This price corresponds to the latest H2A forecourt production analysis price of $3.50 in 2005 dollars ($3.83 in 2009 dollars) utilizing steam methane reforming of natural gas [29]. (The H2A production model is an Excel-based tool that performs a discounted cash flow analysis over a time period based on user inputs and economic assumptions to calculate the cost of hydrogen.)

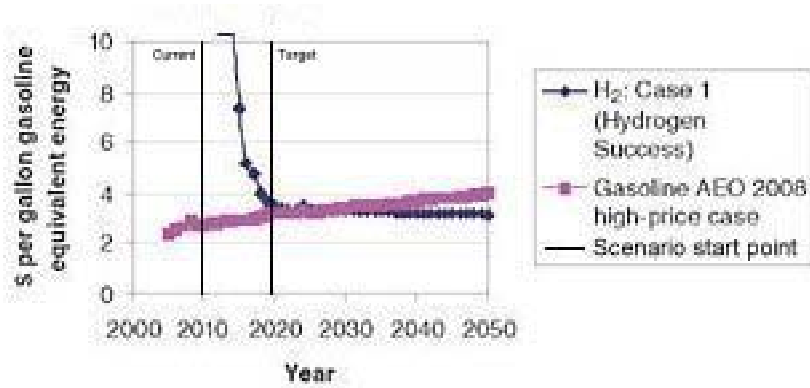

Figure 1 – Hydrogen Fuel Prices, Scenarios 1 and 2 [23]

Maintenance

For the consumer portion of the calculation tool, scheduled maintenance information for the Chevrolet Malibu, Ford Fusion, Nissan Altima, Toyota Camry (conventional ICE and mild HEV), and Toyota Prius (full HEV) was obtained from OEM owner's manuals and maintenance guides; the Saturn Aura was excluded since that model was discontinued in 2009. Details such as manufacturer's recommended service intervals for each vehicle as well as specific maintenance items performed at those intervals were obtained. The estimated expense to maintain these mid-size sedans was calculated using the RepairPrice Estimator [30] in 2009 dollars. Maintenance costs over a five-year period were calculated and included all scheduled maintenance. These costs included an averaged labor cost (the average of expected labor cost at the dealer and expected labor cost at a private shop) as well as an averaged parts cost (high and low). Ten cities, including Boston, Chicago, Cleveland, Denver, Houston, Los Angeles, Miami, New York, San Francisco, and Seattle, were used to determine a "national" average. This 10-city average became the baseline for maintenance costs. Future maintenance costs were estimated using the historical CPI-U for Maintenance and Repairs [31] by fitting a curve to the data and using the curve to forecast increases in maintenance costs. FCV maintenance costs were adjusted from the conventional ICE vehicle maintenance costs by the ratios used in the National Energy Modeling System (NEMS) model [25] for FCVs. Years not provided in the NEMS inputs were interpolated by using a best fit curve.

For fleet vehicles, Vincentric's Vinbase Online for Fleets [32] was used to calculate maintenance costs in 2009 dollars. The same make and model vehicles and the same 10 cities were considered as were used for the consumer vehicles. However, a three-year ownership period was used instead of the five-year period that was used for consumer ownership. Again, the same projected CPI-U for Maintenance and Repairs [31] that was used in the consumer portion of the calculation tool was applied to the fleet portion to project future maintenance costs. Fleet FCV maintenance costs were adjusted from the fleet conventional ICE vehicle maintenance costs using the NEMS input ratios for FCV maintenance [25].

Tires

It was assumed that a set of long-life radial tires would last 60,000 miles prior to needing replacement [33] for a conventional ICE vehicle. However, a switch to low rolling resistance (LRR) tires will more than likely be necessary to help OEMs meet the new Corporate Average Fuel Economy (CAFE) standards due to be instituted in 2016. These LRR tires typically have a tread wear life of 30,000 to 50,000 miles [34-36]. For the purposes of this study, it was assumed that the average LRR tire would need to be replaced after 40,000 miles. OEMs already equip mild and full HEVs with LRR tires to help improve vehicle fuel economy; it was assumed that FCVs would likewise be equipped with LRR tires. The cost to replace one set of tires was estimated with data from the detailed maintenance information from IntelliChoice's cost of ownership estimator [37] in 2009 dollars. The average tire replacement cost was determined for the Chevrolet Malibu, Ford Fusion, Nissan Altima, Toyota Camry (conventional ICE, mild HEV, and FCV), and Toyota Prius (full HEV). Future replacement tire costs were estimated using projections developed from the historical CPI-U for Tires [38]. As was done with the maintenance data, a best fit curve was used with the CPI-U tire data to project future increases for tire costs.

Repairs

For the consumer case, the expense to repair a vehicle for an item that is not covered under the manufacturer's warranty was calculated using the National Automobile Dealers Association's (NADA's) 5-Year Car Cost of Ownership [39] estimator. Repair costs for the five-year ownership period of a Chevrolet Malibu, Ford Fusion, Nissan Altima, Toyota Camry, and Toyota Prius were investigated. As with the maintenance data, the costs in the same 10 cities were used and averaged together to form a "national" average. The 10-city average served as the baseline for repair costs. The best fit curve from the historical CPI-U data for Maintenance and Repairs [31] previously used in the maintenance calculation was again utilized to determine future increases to repair costs. The authors compared the powertrain components of the Honda FCX Clarity (i.e. powerplant power, battery pack voltage, motor power) to that of the mild and full HEVs in this study. It was determined that the Honda FCX Clarity's powertrain components more closely match the mild HEV than the full HEV. Therefore, it was assumed that the FCV would have similar repair costs to those of mild HEVs.

For fleet vehicles, Vincentric's Vinbase for Fleets [32] was used to calculate repair costs in 2009 dollars. The same make/model vehicles and the same 10 cities were considered as were used for the consumer vehicles. However, a three-year ownership period (typical for fleets) was investigated instead of the five-year period that was used for consumer ownership. Again, the same projected CPI-U for Maintenance and Repairs [31] that was used in the consumer portion of the calculation tool was applied to the fleet portion to project future repair costs.

OWNERSHIP COSTS

Insurance

For consumers of conventional ICE vehicles and mild and full HEVs, the countrywide average for combined (liability, comprehensive, and collision) auto insurance premiums was estimated using the National Association of Insurance Commissioners Auto Insurance Databases [40]. The data were then used to develop a best fit curve to project future premium costs. Insurance costs for the natural gas Honda Civic GX were investigated and compared to those of its conventional Honda Civic EX counterpart. The percentage increase in insurance premiums from the conventional Honda Civic to the natural gas Civic was then applied to the conventional ICE vehicle's insurance premiums (calculated as described above) to estimate the insurance premiums for FCV owners.

Fleet vehicle insurance costs were calculated using Vinbase Online for Fleets [32] for the conventional ICE vehicle and both mild and full HEVs. As was done with the consumer portion of the calculation tool, the percentage increase from the conventional Honda Civic to the natural gas Civic was applied to the Vincentric data for calculating future FCV insurance costs. Future insurance rates were projected using the historical CPI-U for Motor Vehicle Insurance [41] because historical data on fleet vehicle insurance costs were not available.

State Registration, Taxes, and Fees

This expense consists of the yearly registration costs charged by states, titling fees, as well as the state and local sales tax on the purchase of a vehicle. IntelliChoice's State Fees Chart [42] was used as the basis to determine a national average for all 50 states. The chart was updated to account for recent changes to state sales taxes; a calculated combined tax rate was added if both state and local taxes were levied on the purchase of a new vehicle. The combined tax rate was then averaged together for all 50 states. Likewise, state titling fees and registration costs were averaged to determine a national average. These taxes and fees were assumed to be constant through all the ownership periods. Taxes were calculated in the first year of consumer vehicle ownership using the following equation:

$$\text{Tax}_{\text{CONSUMER}} = \text{MSRP}_{20XX} \times R \qquad (2)$$

Where MSRP is in 2009 dollars, 20XX is the year and R is the average national tax rate. Fleet ownership taxes were calculated in a similar manner:

$$Tax_{FLEET} = Invoice_{20XX} \times R \qquad (3)$$

Where Invoice is in 2009 dollars, 20XX is the year and R is the average national tax rate. Fleet pricing is generally calculated as invoice plus destination charge minus a fleet incentive; the authors have assumed that the destination charge and fleet incentive are equal.

Vehicle Depreciation

The consumer portion of the calculation tool contains NADA resale values [39] for the Chevrolet Malibu, Ford Fusion, Nissan Altima, Toyota Camry, and Toyota Prius. The vehicles' resale values as a percentage of retained MSRP were averaged together (Malibu, Fusion, Altima, and Camry for conventional ICE vehicle and mild HEV; Prius for full HEV). These resale values assume that the vehicle is in a clean, reconditioned state when sold. It was assumed that the 2015 and 2020 vehicles would retain the same percentage of their original MSRP as did the 2010 model year vehicle when sold after five years. The FCV depreciation is calculated using the difference in depreciation percentage between the conventional Honda Civic and the natural gas Civic. This difference is then applied to the conventional ICE vehicle depreciation to calculate the FCV depreciation as a percentage of retained MSRP.

Depreciation, as a percentage of invoice price, for fleet vehicles (conventional ICE and mild and full HEV) was calculated using the Vincentric data [32]. Again, the difference between the conventional and natural gas Honda Civic depreciation was applied to the conventional ICE vehicle Vincentric data to estimate the FCV depreciation. Although FCVs may experience higher rates of depreciation when first introduced to the market in the 2013-2015 timeframe in the Current FCV Scenario, no data were available to determine to determine how depreciation rates may vary as function of market maturity. Therefore, the same depreciation rates were used in both the Target FCV Scenario and the Current FCV Scenario.

Financing

The expense of the interest on a consumer vehicle loan was calculated from consumer credit data [43] and bank prime rates [44] from the Federal Reserve. Historical interest rates for new car loans at auto finance companies were listed as well as average maturity and loan-to-value ratios. A graph of these historical interest rates versus the historical prime rate was developed using a best fit curve to determine the relationship between new car loan rates and the prime rate. A prime rate forecast [45] was then obtained and used to project future new car loan interest rates. The Federal Reserve data [43] indicated that the historical (1993-2009) average new car loan maturity was 57.52 months with an average loan-to-value ratio of 91.77. Therefore, the average consumer puts down 8.23% on a new car loan.

The interest on a fleet vehicle was determined in a similar manner. However, interest rates for 3-month commercial paper [46] were used instead of interest rates from auto finance companies. A similar relationship between the historical prime rate and the 3-month commercial paper rate was established. The forecasted prime rate [45] then was used to predict future 3-month commercial paper rates from the best fit curve. A loan-to-value ratio of 100 was assumed (no money down on the loan).

Tax Credit

Section 1341 of the Energy Policy Act of 2005 (Pub. L. 109-58) provides for the Alternative Fuel Motor Vehicle Credit and includes separate tax credits for four categories of light, medium, and heavy-duty vehicles: hybrids, FCVs, alternative fuel vehicles (dedicated natural gas and propane), and lean-burn diesel vehicles. The credit amount differs by the type of vehicle and is subtracted directly from the total amount of federal tax owed. It covers 50% of the incremental cost of the vehicle, plus an additional 30% of the incremental cost for vehicles meeting super ultra low emissions vehicle (SULEV) and Bin 2 emission standards, and is capped at $5,000 for vehicles with gross vehicle weight ratings (GVWRs) of 8,500 lb or less. The cost per mile calculation tool assumes mild HEVs will qualify for the 50% incremental cost, while full HEVs and FCVs will get the full 80% of the incremental cost covered until the tax credit expires on December 31, 2010.

CALCULATING THE COST PER MILE

The cost-per-mile calculation tool described in this paper assumes that the vehicle is kept for five (consumer) or three (fleet) years [47,48] and then is sold in a clean, reconditioned state. Model years 2015 and 2020 represent new generations of vehicles with the attributes outlined in the Methodology for Calculating Future Vehicle Attributes section. All of the direct costs were calculated in 2009 dollars. However, the calculation tool contains the ability to convert this 2009 dollar amount into any nominal dollar year by using forecasts for the CPI-U [49,50]. To obtain the total annual cost-per-mile for each vehicle type, all of the operating and ownership costs for each of the three- or five-year periods were summed and divided by the annual VMT (which was kept constant). It should be noted that indirect costs were neglected in the calculations of this tool. These may include but are not limited to costs for compliance with vehicle inspection and maintenance programs, accident repairs, congestion, roadway maintenance/construction, parking, and tolls.

RESULTS

Cost-per-mile results are reported only for consumer-operated vehicles travelling 15,000 miles per year [51] and for fleet vehicles travelling 25,000 miles per year [48], though the calculation tool can also be used to assess consumer-operated vehicles travelling 10,000 or 20,000 miles per year and fleet vehicles travelling 20,000 or 30,000 miles per year. Overall results using the tool's default values for the Target FCV Scenario are shown in Figures A1 and A2 (all figures are included in the Appendix). Both figures show that FCVs can be competitive with conventional ICE vehicles as well as full HEVs if DOE cost targets are met, even without federally-mandated tax credits that are applied only in the first ownership period for both consumers (2010-2014) and fleets (2010-2012) in this analysis. This analysis validates that the DOE targets/goals must be achieved for FCVs to be commercially competitive with other vehicle powertrains. Detailed results for each powertrain and ownership type are shown in Figures A3-A10. These results show that FCVs may be more competitive on a cents-per-mile basis than mild HEVs if the DOE targets are achieved. Mild HEVs cannot compete with the other powertrains in this scenario due to their: 1) high MSRP (large financing expenditures); 2) high depreciation rate (low residual value); and 3) lower fuel economy relative to full HEVs and FCVs (high fuel costs). Across all powertrains, depreciation is the largest contributor to direct costs in calculating the cost per mile.

The Current FCV Scenario overall results for consumer and fleet ownership are shown in Figures A11 and A12, respectively. Note that there are no results for FCVs in the first ownership period for both consumer and fleets as FCVs do not enter the market until 2013 in this scenario. Contrasting with the Target FCV Scenario, the Current FCV Scenario shows that to be competitive with conventional ICE vehicles and HEVs during the early stages of commercial implementation, FCVs will need tax credits or other forms of subsidies. The detailed results for the Current FCV Scenario (Figures A13-A20) again show depreciation and financing expenditures as the major costs for the FCV. High FCV MSRP is likely to be a market barrier at least initially when FCVs are introduced. However, if the DOE cost targets can be met for all FCV subsystem components, the cost-per-mile differential compared to other vehicle powertrain technologies will be kept to a minimum.

SUMMARY/CONCLUSIONS

The authors have created a new cost-per-mile calculator that allows for comparison among several advanced powertrains, including a conventional ICE vehicle, mild and full HEV, and FCV. This flexible tool contains default data sets for both consumer and fleet ownership and includes the ability to analyze the cost-per-mile over several ownership periods, which today's calculators do not provide. Two scenarios were chosen for analysis: one defines a mature, market-ready FCV technology and hydrogen fueling infrastructure in 2010; the other examines a "market introduction" case with FCVs as an emerging technology in the 2013-2015 timeframe with an immature hydrogen fueling infrastructure. In both scenarios, the largest contributor to the total cost-per-mile is vehicle depreciation. If uncertainties in factors such as fuel cell stack durability and hydrogen fuel availability can be eliminated, the depreciation differential between the FCV and its gasoline counterparts could be reduced.

While Toyota and Hyundai-Kia intend to bring FCVs to the future market, several manufacturers are either producing plug-in HEVs (PHEVs) or are in the process of readying them for the market. Since PHEVs will be openly competing against the powertrains presented in this study, the authors intend to add this technology to a future iteration of the cost-per-mile calculator.

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CONTACT INFORMATION

Alliance Technical Services, Inc.
10816 Town Center Blvd., Suite 232
Dunkirk, MD 20754
www.alliance-technicalservices.com

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DEFINITIONS/ABBREVIATIONS

BLS	Bureau of Labor Statistics
CAFE	Corporate Average Fuel Economy
CPI-U	Consumer Price Index, All Urban
DOE	Department of Energy
EPA	Environmental Protection Agency
FCV	fuel cell vehicle
GVWR	gross vehicle weight restriction
H2A	Hydrogen Analysis
HEV	hybrid electric vehicle
ICE	internal combustion engine
kg	kilogram(s)
kW	kilowatt(s)
kWh	kilowatt-hour(s)
lb	pound(s)
LRR	low rolling resistance
mpg	miles per gallon
MSRP	manufacture’s suggested retail
OEM	original equipment manufacturer
NADA	National Automobile Dealers
RPE	retail price equivalent
SULEV	super ultra low emissions vehicle
VMT	vehicle miles traveled

APPENDIX

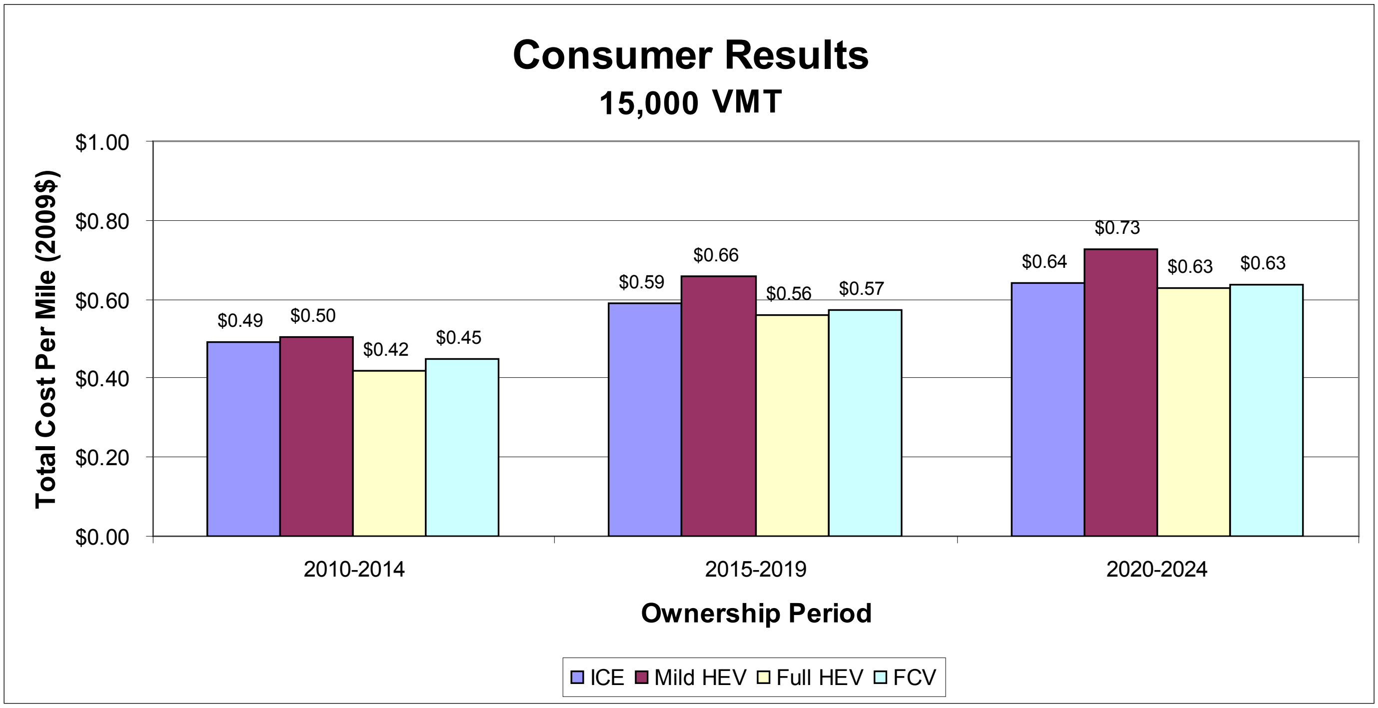

Figure A1 – Target FCV Scenario Overall Results for Consumer-Owned Vehicles

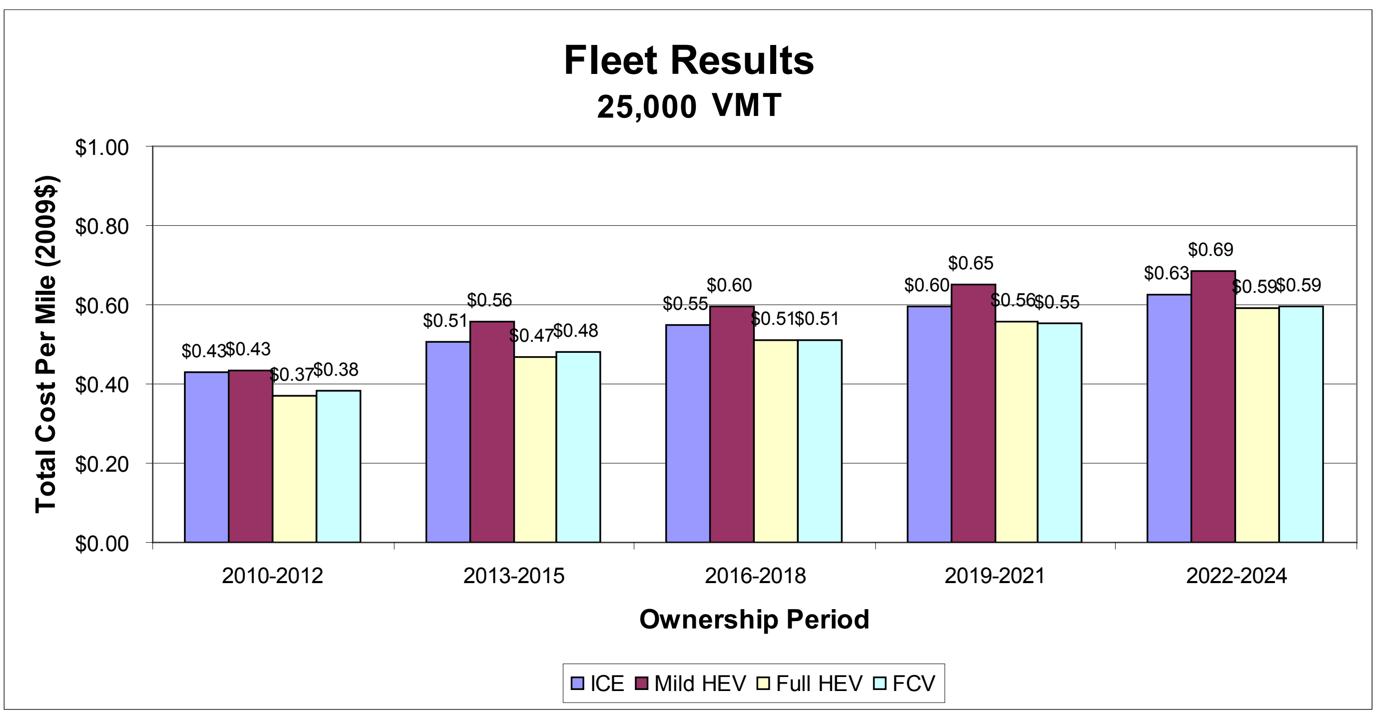

Figure A2 – Target FCV Scenario Overall Results for Fleet-Owned Vehicles

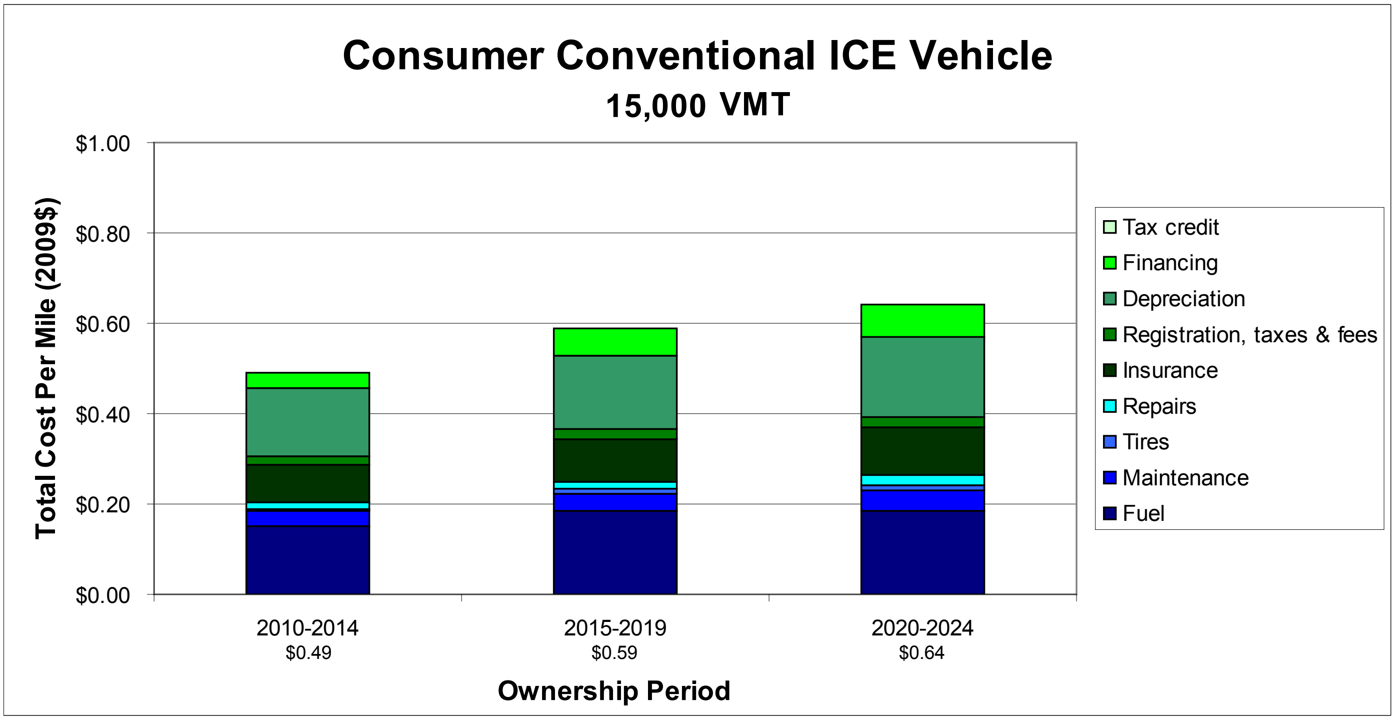

Figure A3 – Target FCV Scenario Detailed Results for a Consumer Owned-Conventional ICE Vehicle

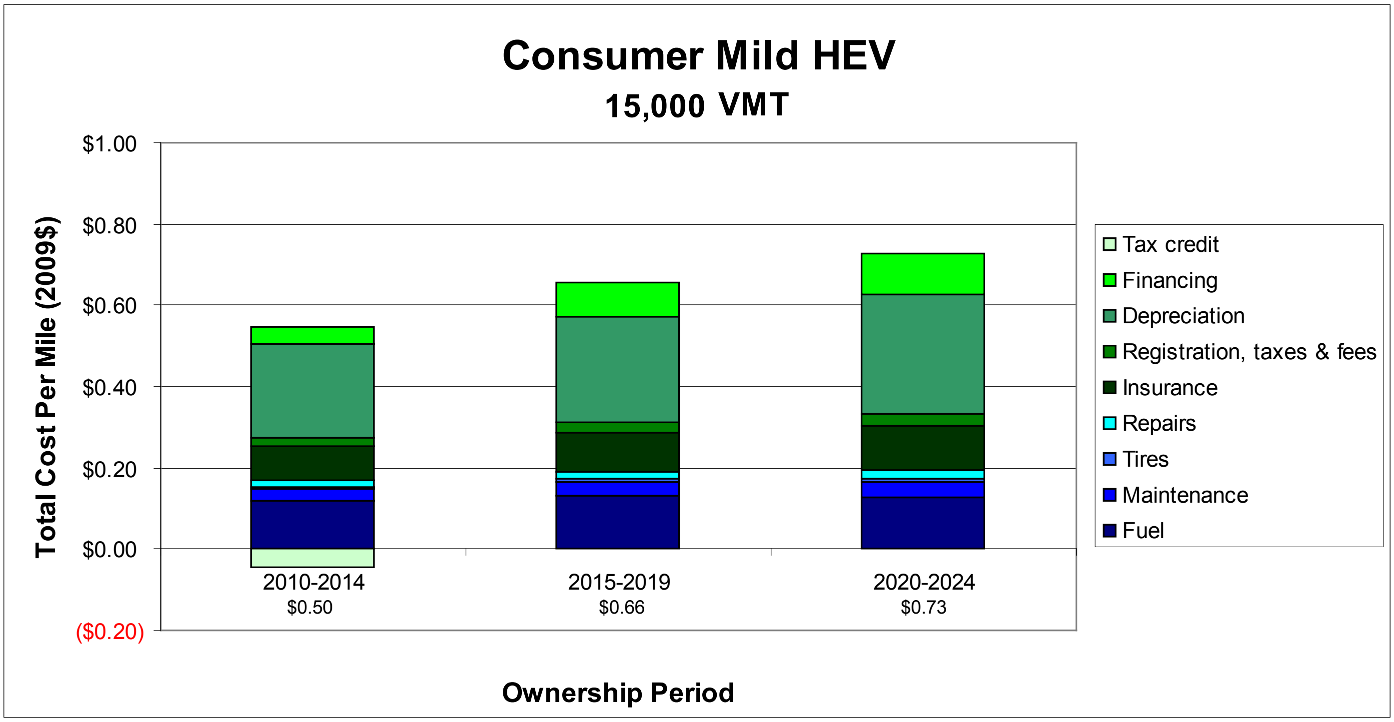

Figure A4 – Target FCV Scenario Detailed Results for a Consumer-Owned Mild HEV

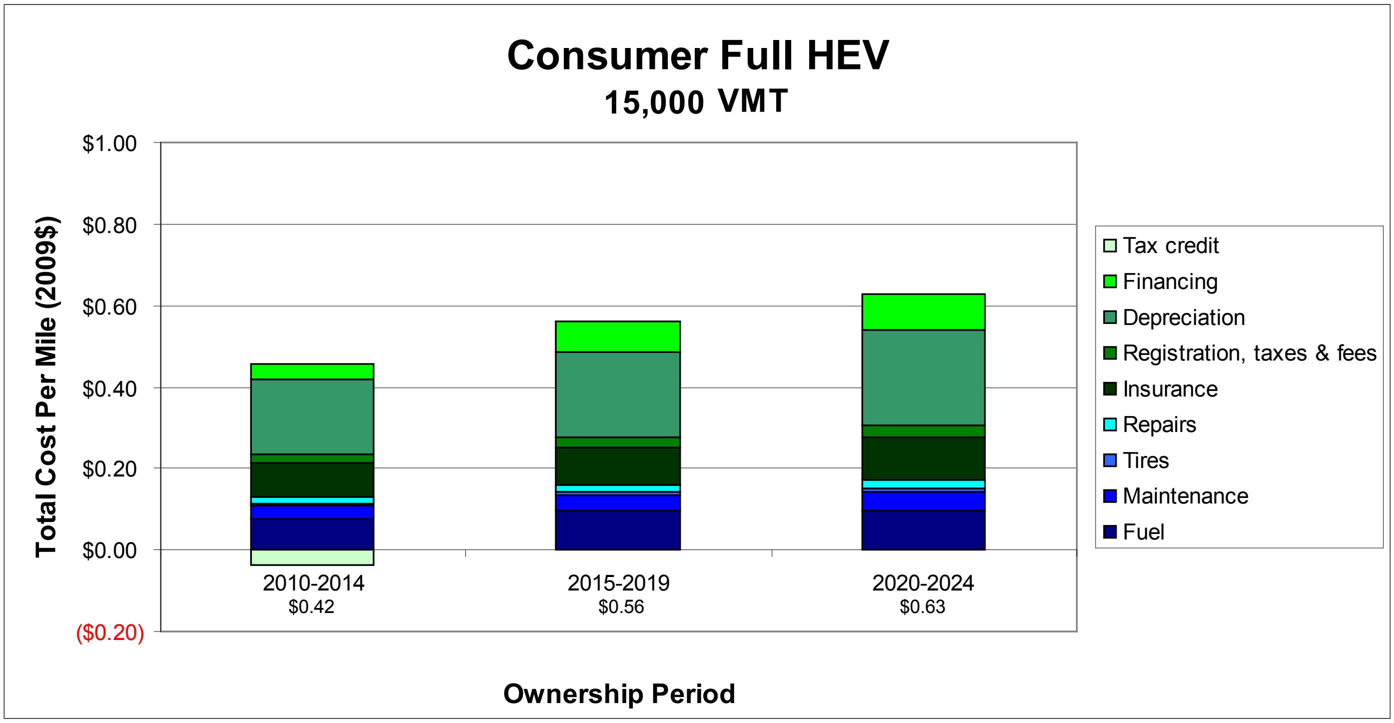

Figure A5 – Target FCV Scenario Detailed Results for a Consumer-Owned Full HEV

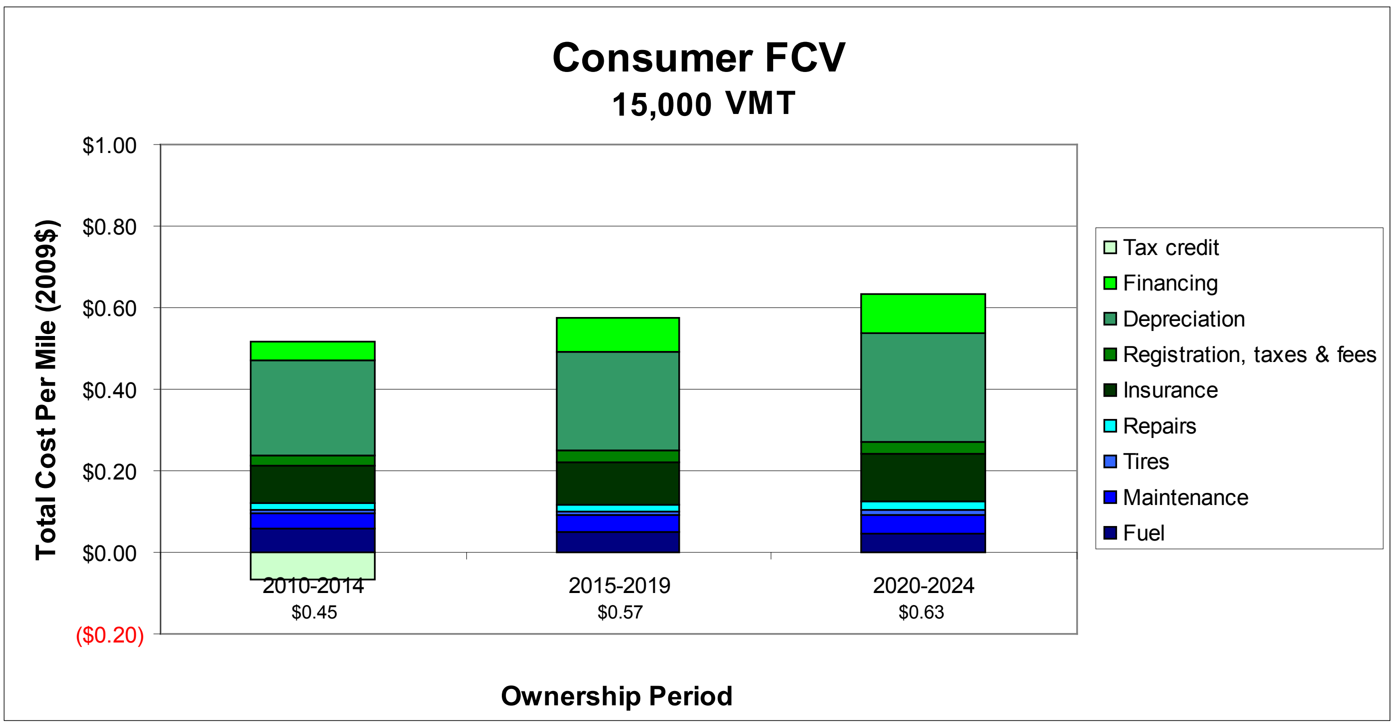

Figure A6 – Target FCV Scenario Detailed Results for a Consumer-Owned FCV

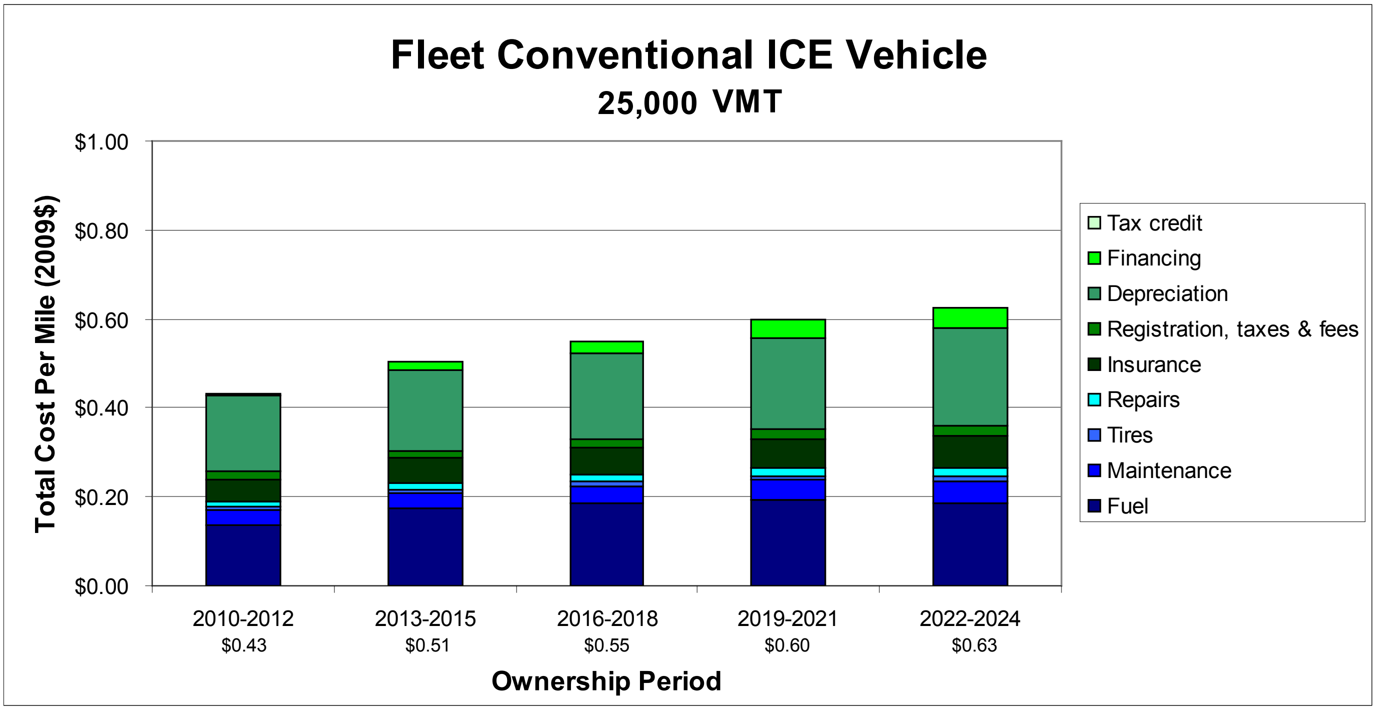

Figure A7 – Target FCV Scenario Detailed Results for a Fleet-Owned Conventional ICE Vehicle

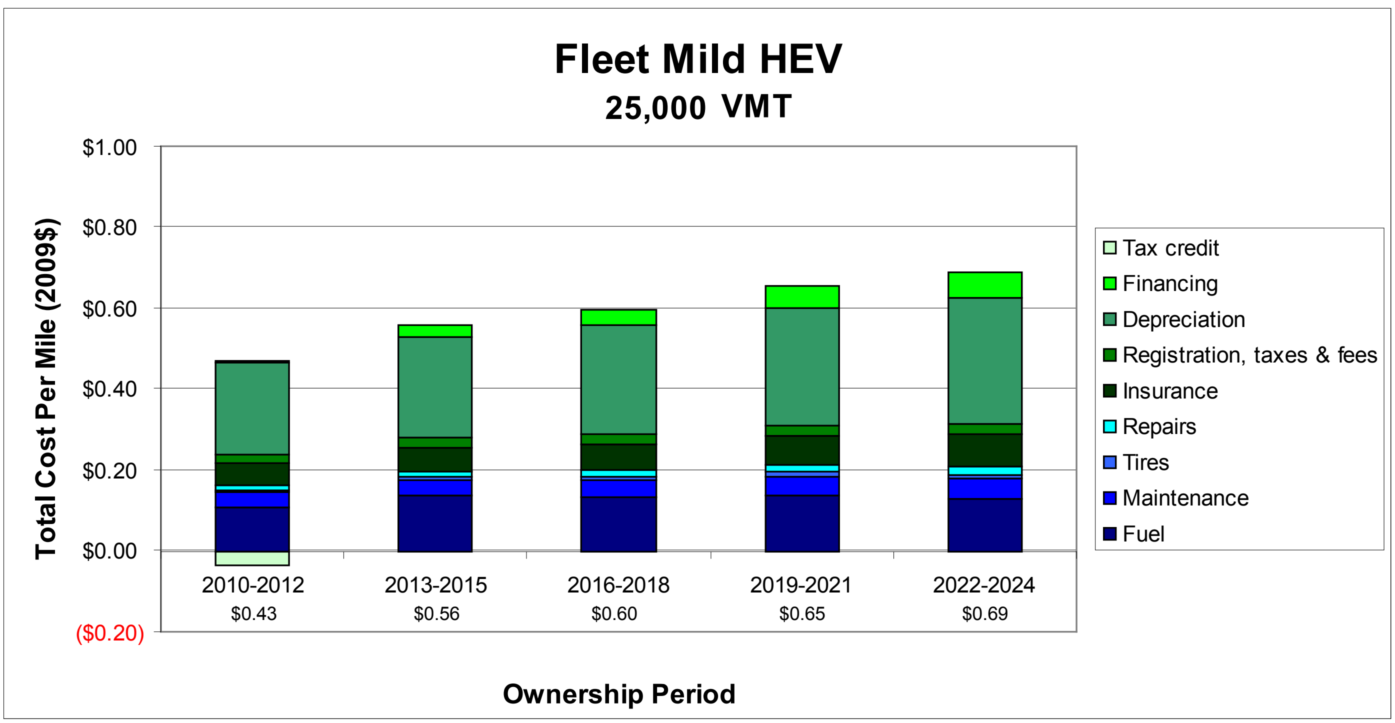

Figure A8 – Target FCV Scenario Detailed Results for a Fleet-Owned Mild HEV

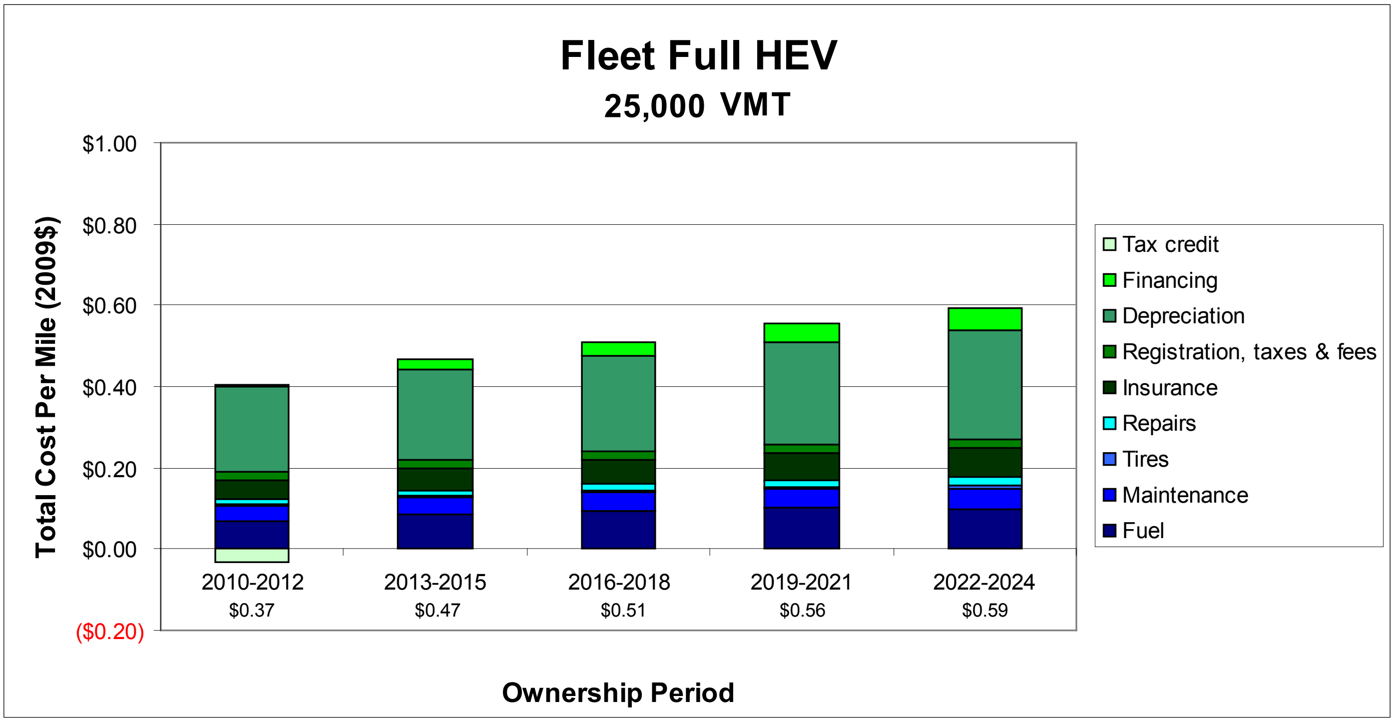

Figure A9 – Target FCV Scenario Detailed Results for a Fleet-Owned Full HEV

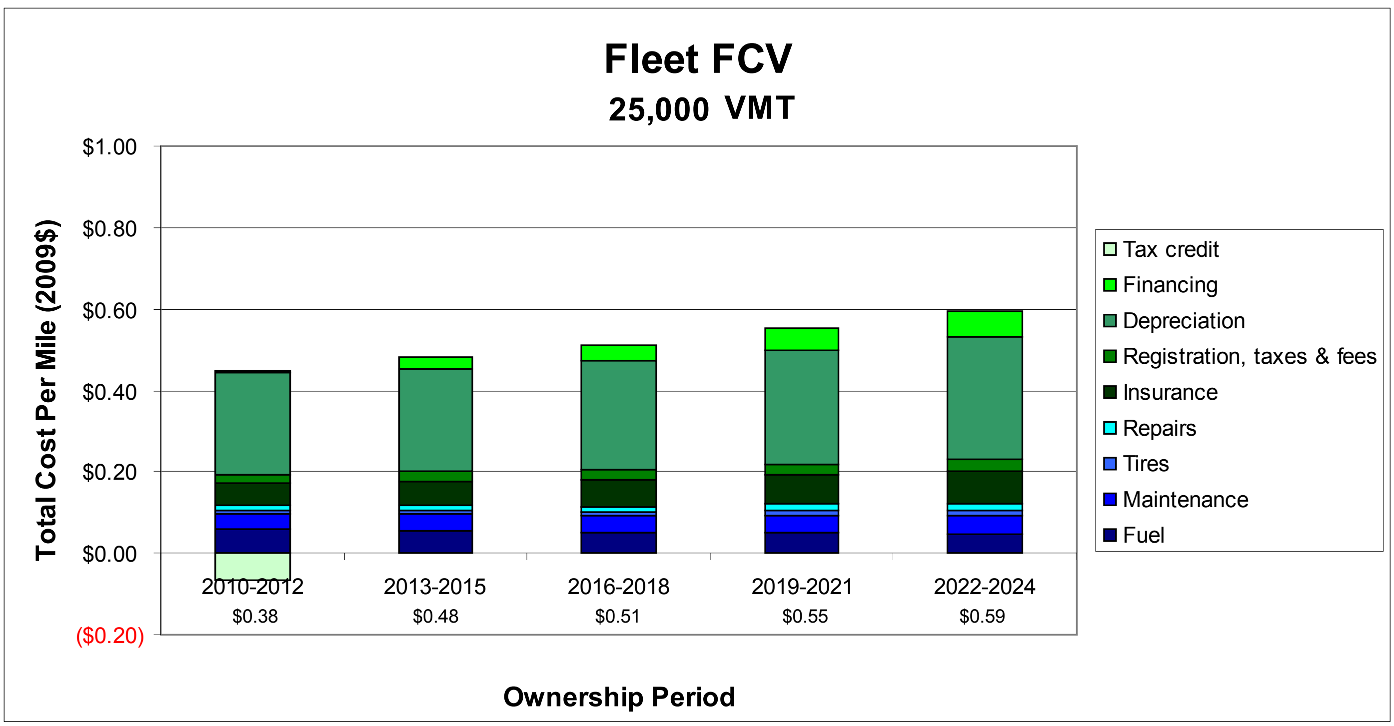

Figure A10 – Target FCV Scenario Detailed Results for a Fleet-Owned FCV

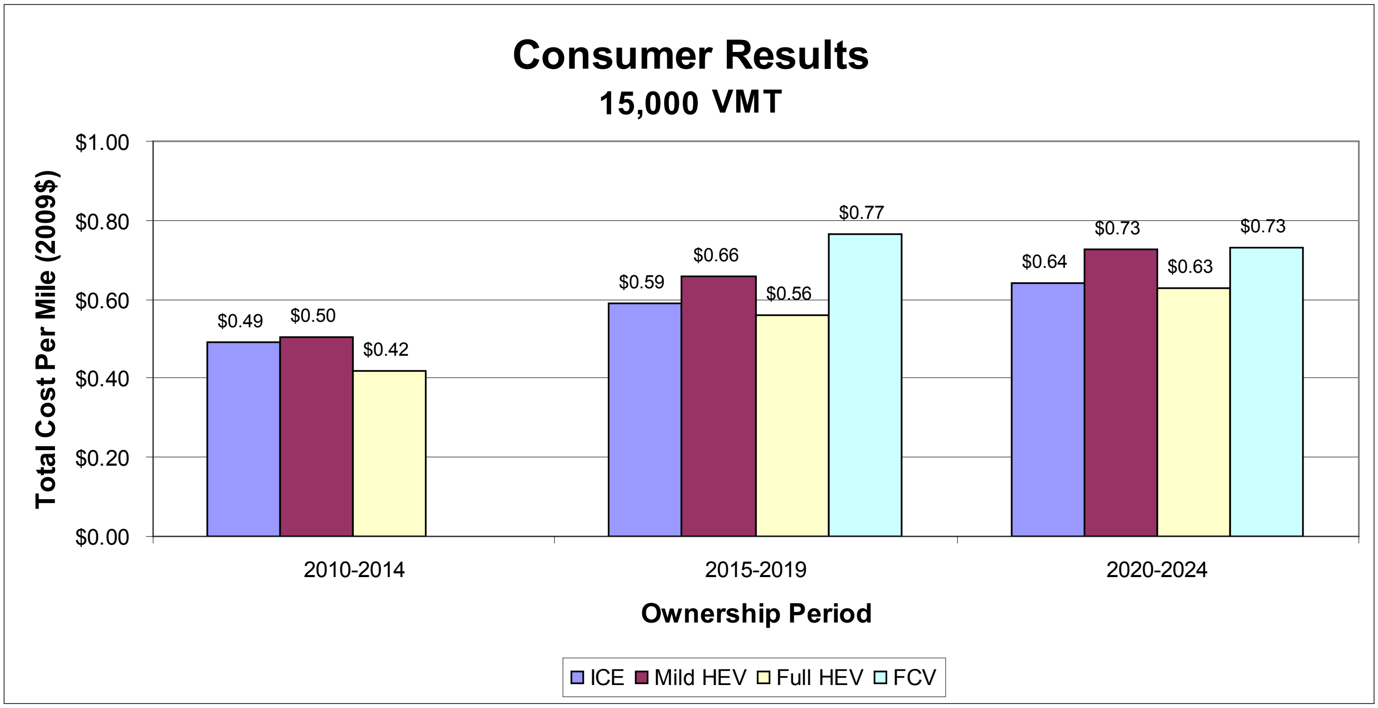

Figure A11 – Current FCV Scenario Overall Results for Consumer-Owned Vehicles

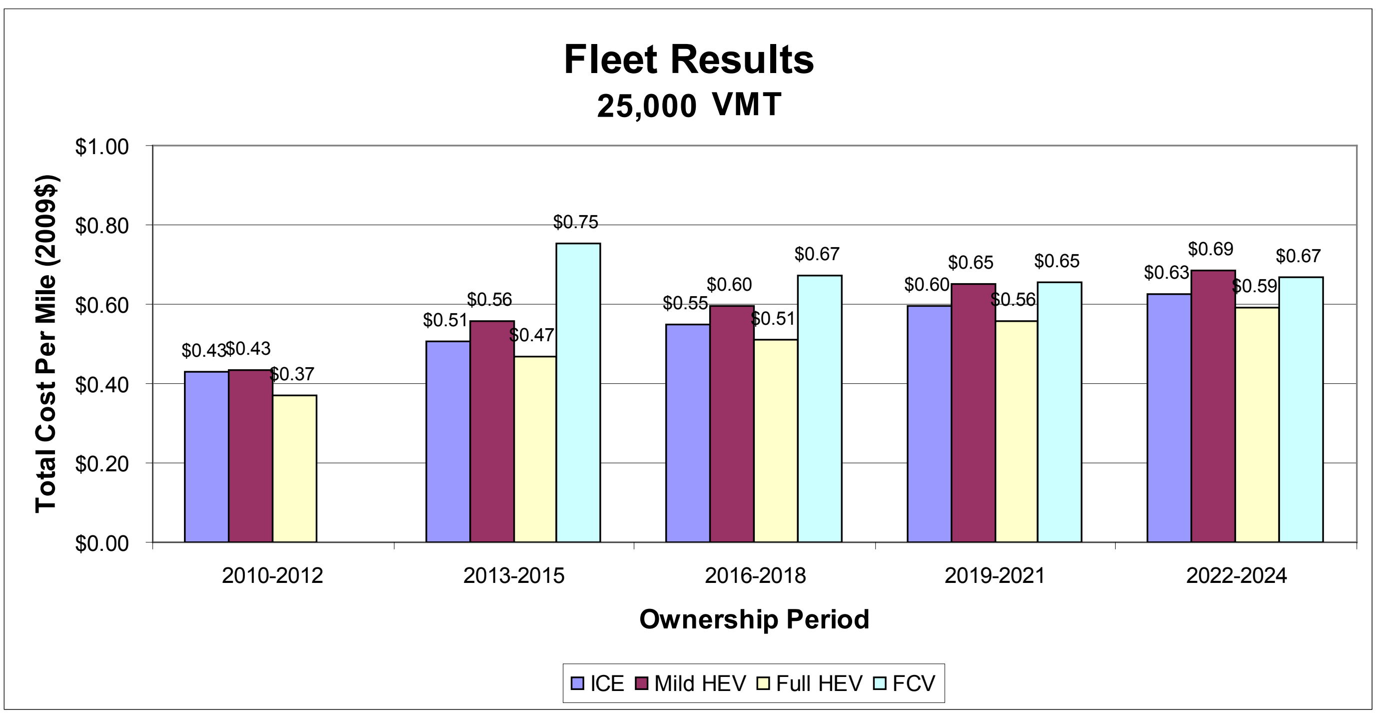

Figure A12 – Current FCV Scenario Overall Results for Fleet-Owned Vehicles

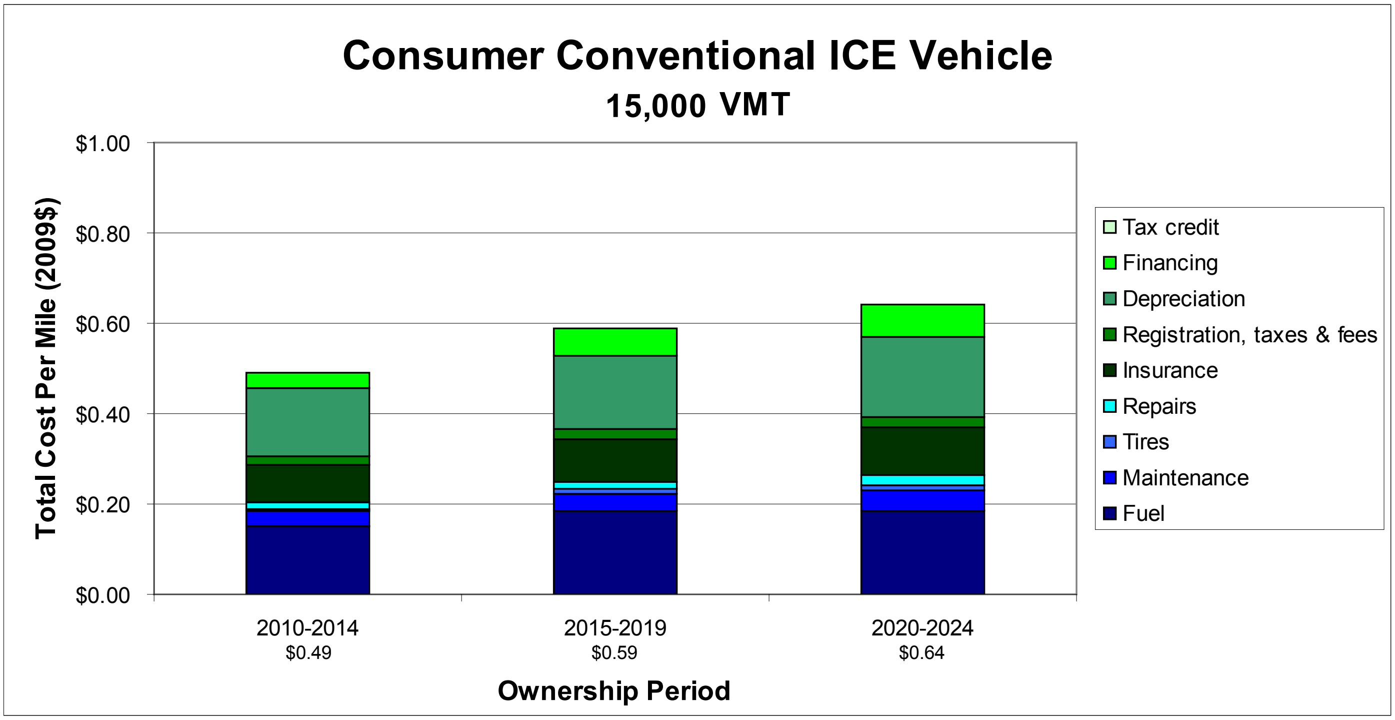

Figure A13 – Current FCV Scenario Detailed Results for Consumer Owned-Conventional ICE Vehicle

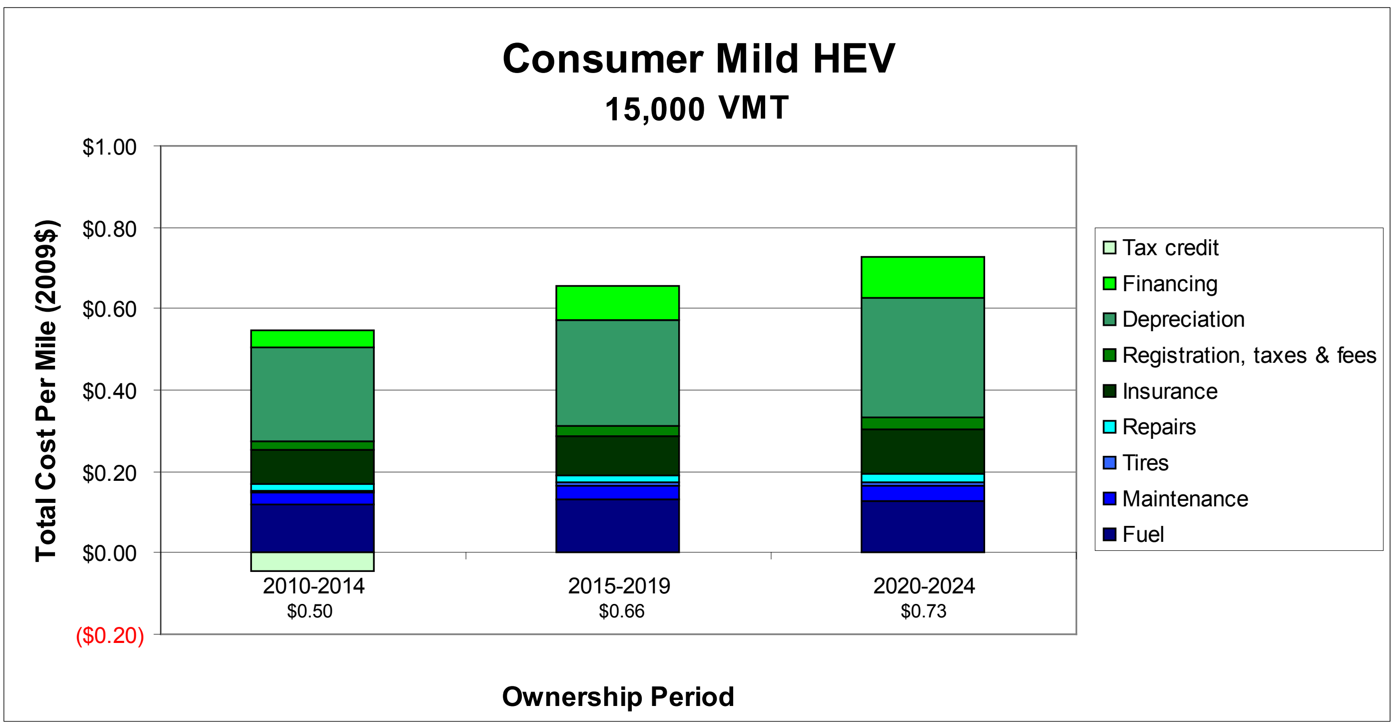

Figure A14 – Current FCV Scenario Detailed Results for Consumer-Owned Mild HEV

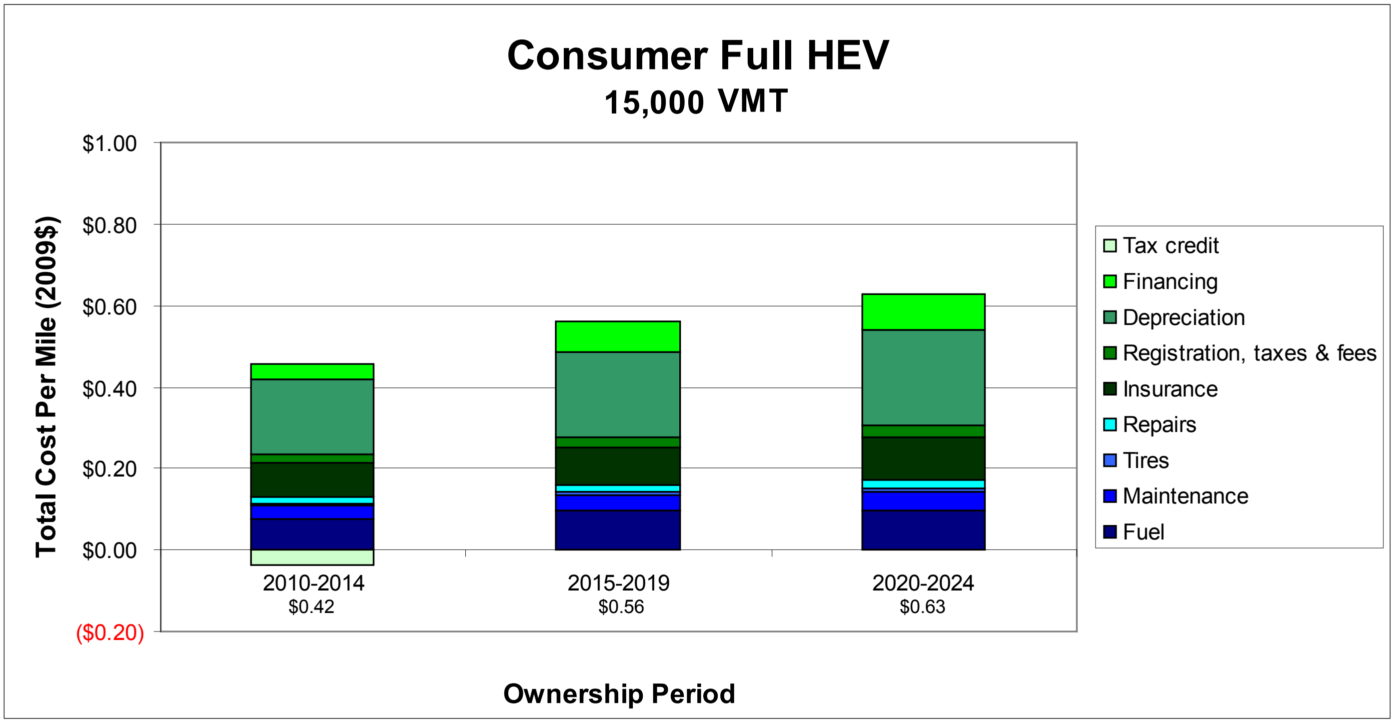

Figure A15 – Current FCV Scenario Detailed Results for Consumer-Owned Full HEV

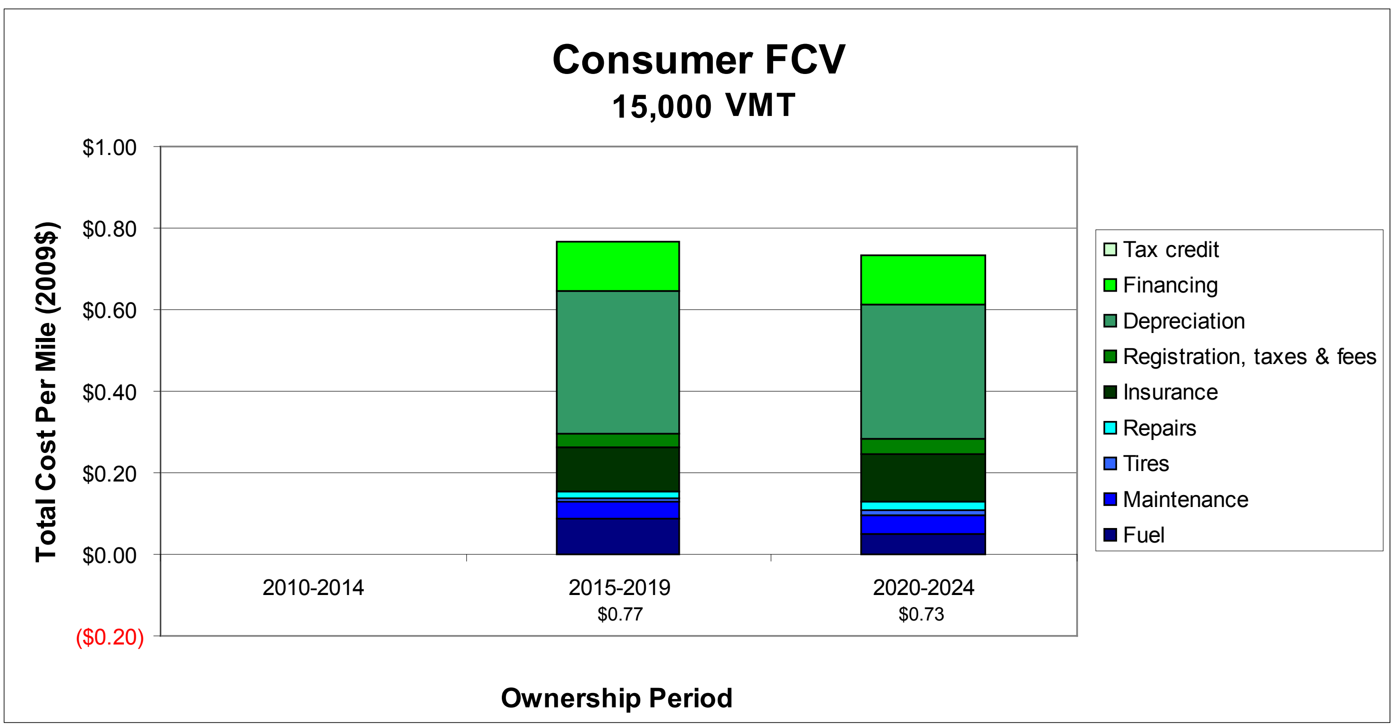

Figure A16 – Current FCV Scenario Detailed Results for Consumer-Owned FCV

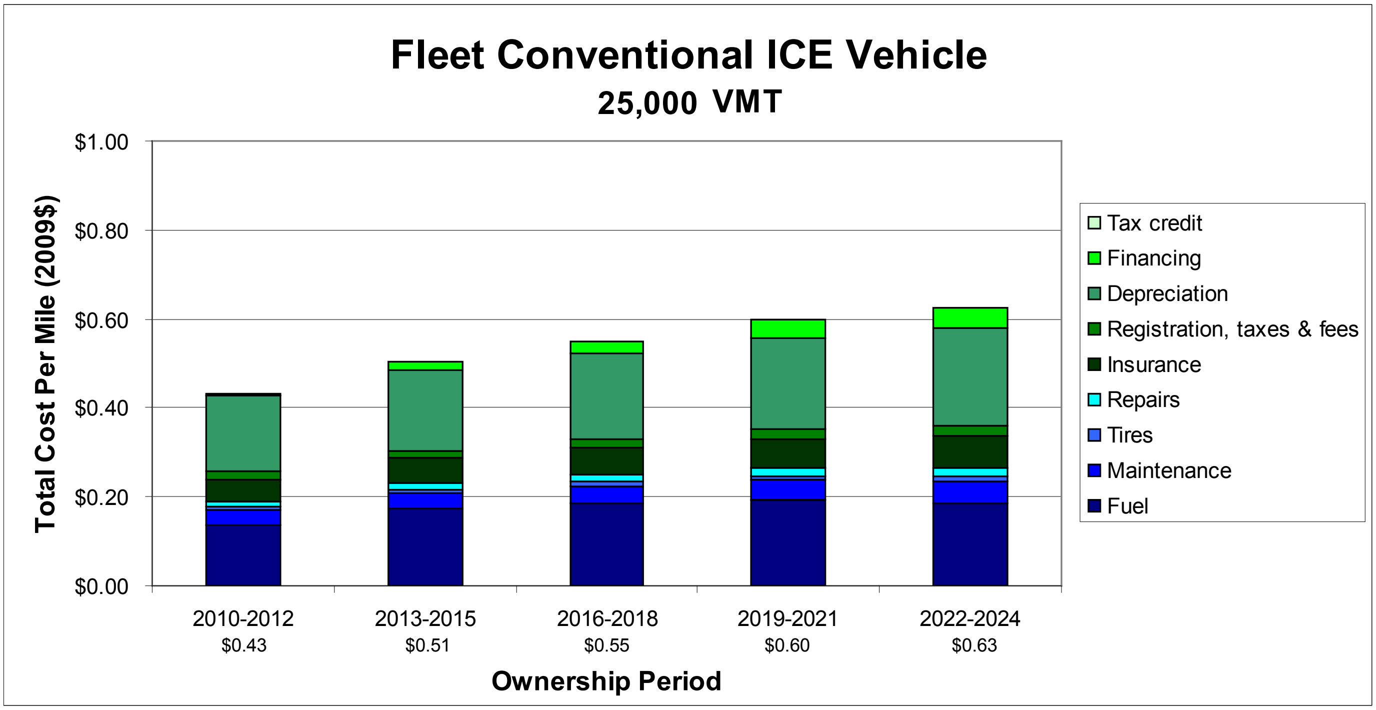

Figure A17 – Current FCV Scenario Detailed Results for Fleet-Owned Conventional ICE Vehicle

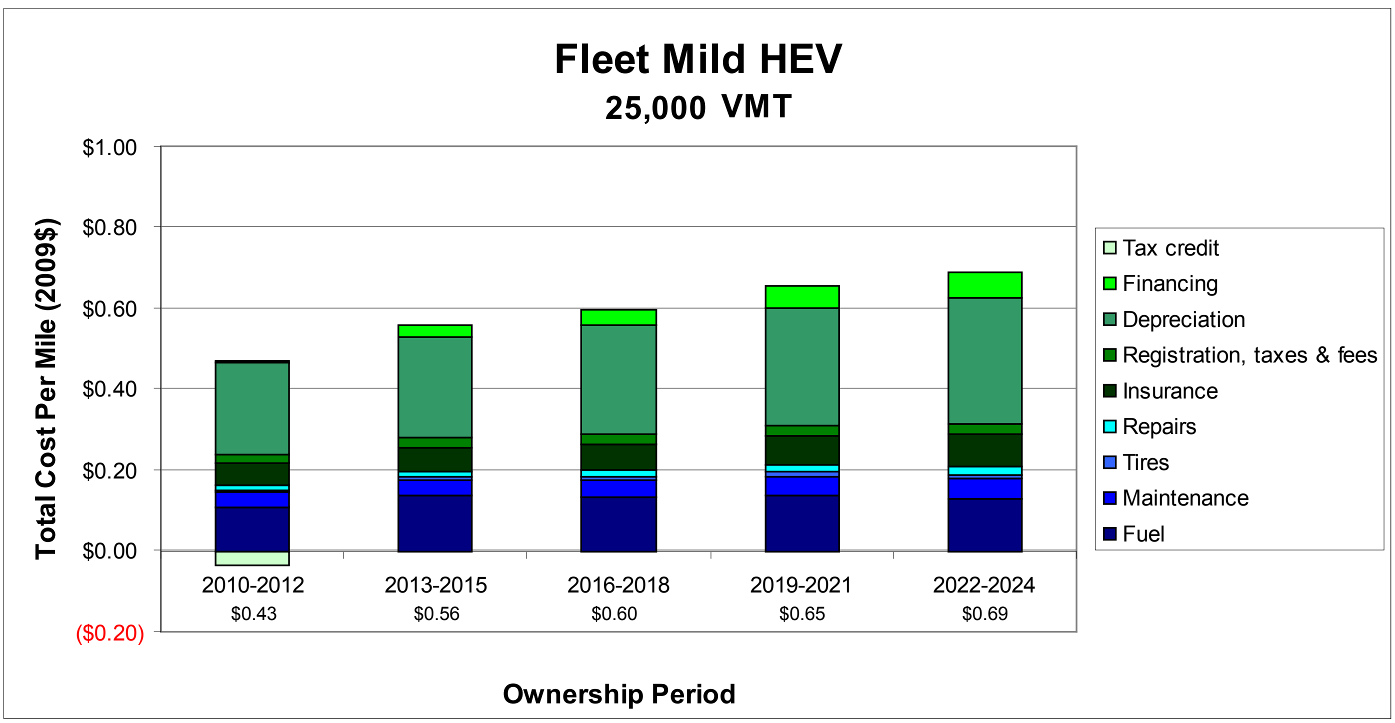

Figure A18 – Current FCV Scenario Detailed Results for Fleet-Owned Mild HEV

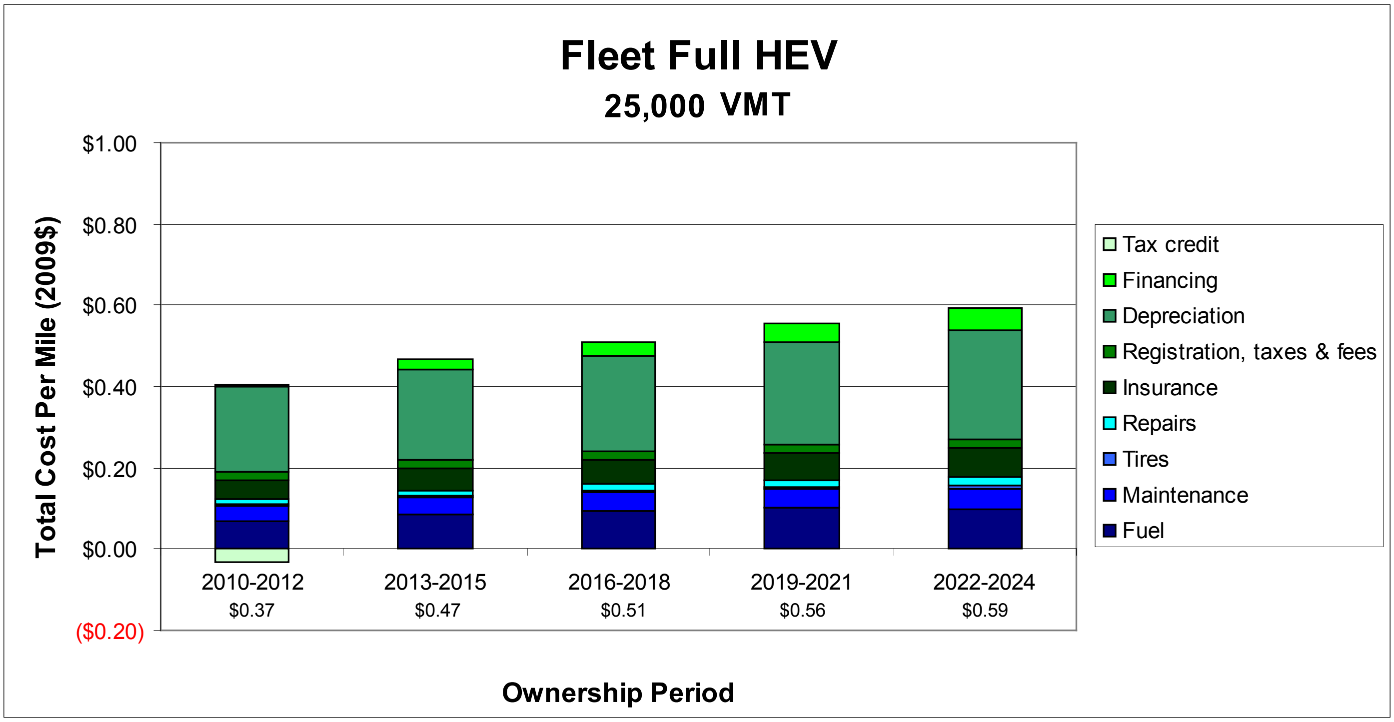

Figure A19 – Current FCV Scenario Detailed Results for Fleet-Owned Full HEV

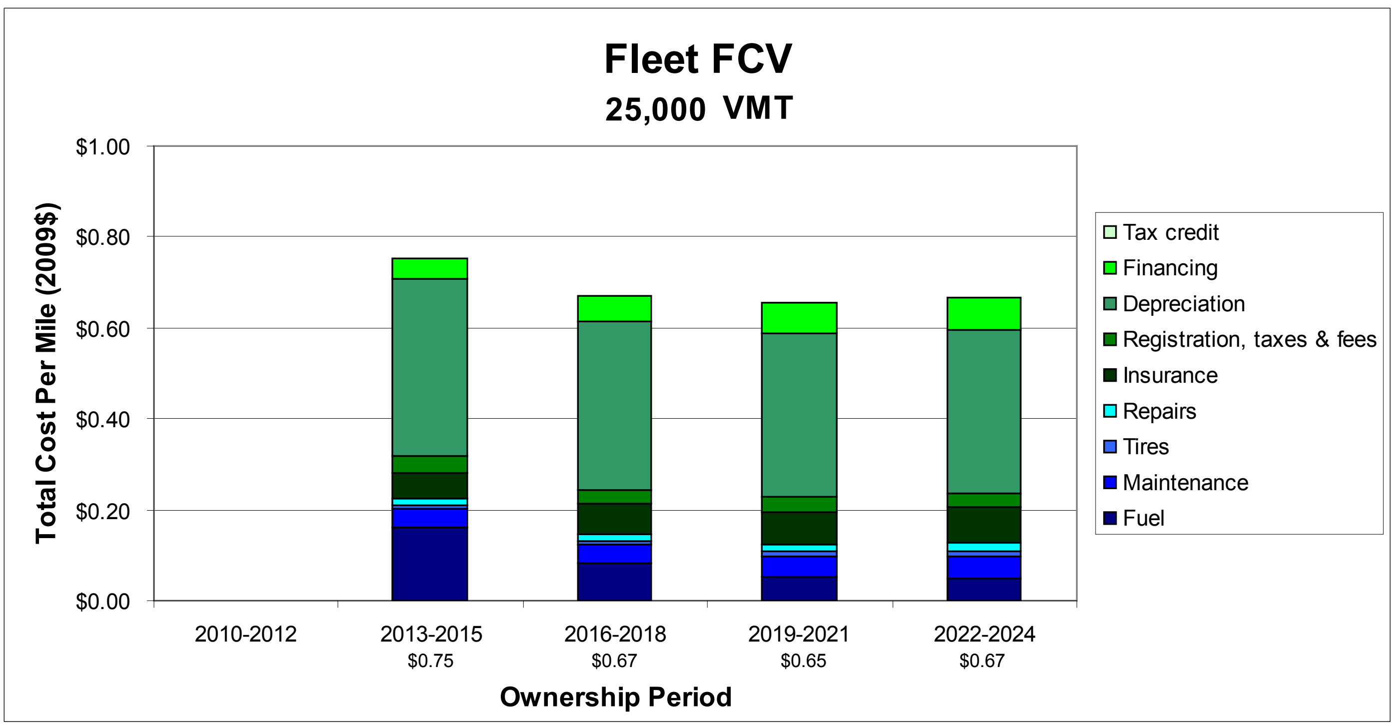

Figure A20 – Current FCV Scenario Detailed Results for Fleet-Owned FCV

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14. ABSTRACT *(Maximum 200 Words)*
Currently, several cost-per-mile calculators exist that can provide estimates of acquisition and operating costs for consumers and fleets. However, these calculators are limited in their ability to determine the difference in cost per mile for consumer versus fleet ownership, to calculate the costs beyond one ownership period, to show the sensitivity of the cost per mile to the annual vehicle miles traveled (VMT), and to estimate future increases in operating and ownership costs. Oftentimes, these tools apply a constant percentage increase over the time period of vehicle operation, or in some cases, no increase in direct costs at all over time. A more accurate cost-per-mile calculator has been developed that allows the user to analyze these costs for both consumers and fleets. The calculator was developed to allow simultaneous comparisons of conventional light-duty internal combustion engine (ICE) vehicles, mild and full hybrid electric vehicles (HEVs), and fuel cell vehicles (FCVs). This paper is a summary of the development by the authors of a more accurate cost-per-mile calculator that allows the user to analyze vehicle acquisition and operating costs for both consumer and fleets. Cost-per-mile results are reported for consumer-operated vehicles travelling 15,000 miles per year and for fleets travelling 25,000 miles per year.

15. SUBJECT TERMS
Cost-per-mile; Cost-per-mile calculator; Vehicle Powertrain Technologies; hybrid electric vehicles; HEV; fuel cell vehicles; FCV; internal combustion engine vehicle; ICE; vehicle fleet

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