Hybrid-Electric Vehicle Design
Retail and Lifecycle Cost Analysis

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Final Report

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Abbreviations and Acronyms

AF1 = advanced / full HEV 1 case
AF2 = advanced / full HEV 2 case
Ah = ampere hour or ampere hours
AM = advanced / mild HEV case
BPM = brushless permanent magnet
BEV = battery-powered electric vehicle
CARB = California Air Resources Board
DOE = U.S. Department of Energy
DOT = U.S. Department of Transportation
DOHC = dual overhead camshaft
EIA = Energy Information Administration
EV = electric-drive vehicle
FCV = fuel cell electric vehicle
FUDS = federal urban driving schedule
g = gram or grams
GDI = gasoline direct injection
GHG = greenhouse gas
HEV = hybrid electric vehicle
HHV = higher heating value
ICE = internal-combustion engine
ICEV = internal-combustion engine vehicle
ISG = integrated starter generator
kg = kilogram or kilograms
kW = kilowatt or kilowatts
kWh = kilowatt hour or kilowatt hours
L = liter or liters
lb = pound
LHV = lower heating value
MF = moderate / full HEV case
MM = moderate /mild HEV case
m&r = maintenance and repair
NiMH = nickel-metal hydride
OEM = original equipment manufacturer
SUV = sport utility vehicle
U.S. = United States
V = volt or volts
VMT = vehicle miles traveled
VTEC = variable valve-timing and electronic lift-control
W = watt or watts
Wh = watt hour or watt hours
ZEV = zero-emission vehicle

Abstract

Various types of electric-drive and other clean-fuel vehicles continue to be of interest as a means to control motor vehicle pollution and to curb petroleum use both in the U.S. and in many other countries. Since travel behavior is difficult to change, many analysts believe that modifying vehicle technology is the best means to offset the environmental impacts of continued increases in vehicle miles traveled (VMT) in areas where automobile use is dominant. Hybrid-electric vehicles (HEVs) are one vehicle type that can reduce petroleum use and greenhouse gas emissions, and also help enable low emissions of other pollutants. Toyota and Honda are currently commercializing HEV models, with other automakers bringing HEVs to market over the next few years.

Presented here is one analysis of the manufacturing costs, retail prices, and lifecycle costs of five different HEV types in high-volume production in the year 2010 timeframe. There vehicles types include compact, mid-sized passenger car, large pickup truck, minivan, and sport-utility vehicle. For purposes of this analysis, we have updated and made major modifications to a detailed motor vehicle retail and lifecycle cost spreadsheet model that we have previously used to analyze the costs of various types of conventional vehicles, electric-drive vehicles, and other alternative-fuel vehicles. We have then combined the use of this cost model with a HEV design and performance analysis performed by our colleagues using the Advisor vehicle simulation model. This analysis has produced five different HEV designs for each vehicle type (for a total of 25 primary HEV cases and a set of five baseline gasoline vehicles for comparison).

This integration of an HEV design and performance analysis with our HEV retail price and lifecycle cost modeling framework and analysis has resulted in the following primary results and key insights:

- the "HEV Price Effects" of the various options range from $2,543 (Cavalier AM case) to $6,694 (Silverado MF case) and are as follows, based on the estimated full retail price of the vehicles to consumers:

Vehicle Type	HEV Price Effect (Year 2000 $s)				
	MM Case	MF Case	AM Case	AF1 Case	AF2 Case
Cavalier	$2,697	$4,251	$2,543	$3,726	$3,385
Taurus	$2,756	$4,382	$2,578	$4,240	$3,795
Silverado	$3,778	$6,694	$3,390	$5,287	$4,823
Caravan	$3,162	$4,827	$2,766	$4,388	$3,930
Explorer	$3,461	$5,719	$3,534	$5,209	$4,726

Notes:
MM = moderate package of improvements, mild hybridization; MF = moderate package of improvements, full hybridization; AM = advanced package of improvements, mild hybridization; AF1 = advanced package of improvements, full hybridization case 1; AF2 = advanced package of improvements, full hybridization case 2/

- the vehicle lifecycle cost disparities between the HEVs and baseline vehicles are somewhat lower in relative terms than the retail price differences, with lifecycle costs of some HEVs (and particularly the AM designs) in some cases being very similar to those of the baseline vehicles even though their retail prices are a few thousand dollars higher;

- the gasoline breakeven prices that we calculate for the various HEVs in comparison with the baseline ICEVs range from $1.49 per gallon to $2.65 per gallon, and the low end of this range is very close to the $1.46 per gallon assumed U.S. national average price in the study, again suggesting that at least a few of the HEV designs are very close to being economically competitive on a lifecycle cost basis;

- given the various assumptions and estimates used in this analysis, it appears that combining the "advanced package of vehicle improvements" with "mild vehicle hybridization" (AM case) provides what generally is the least-cost solution of the HEV options and that has lifecycle costs very close to those of the baseline vehicles; and

- these AM cases may be close to a set of "optimized" cases in terms of both cost and performance, for the various vehicle types but if fuel economy gains are valued more highly (such as through carbon taxes or oil import externality taxes, or through a "social cost analysis") then the more fuel efficient options, and in particular the AF2 cases, might look attractive as well.

I. Introduction and Problem Context

Various types of electric-drive and other clean-fuel vehicles continue to be of interest as a means to control motor vehicle pollution and to curb petroleum use both in the U.S. and in many other countries. Since travel behavior is difficult to change, many analysts believe that modifying vehicle technology is the best means to offset the environmental impacts of continued increases in vehicle miles traveled (VMT) in areas where automobile use is dominant. In fact, extensive research and development has been conducted on "alternative-fuel" vehicles (AFVs) in recent years, and particularly on the commercialization of natural gas vehicles and electric-drive vehicles (EVs). EV designs powered by batteries, as well as "hybrid" EV designs with combustion engines (HEVs), are now commercial (though the battery-only designs have met with limited market success). Meanwhile, research and development activities on fuel cell-powered EVs (FCVs) have been intense since the early 1990s, and based on the progress made during that time in improving the power density of proton-exchange membrane fuel cells, widespread commercialization of FCVs is expected in about the 2008-2010 timeframe (albeit with significant system cost and durability challenges still to be met).

However, it is important to remember that even the best technological solutions are limited in scope, and no one type of solution can address all of the problems imposed by the car-oriented transportation systems that generally dominate the U.S. For example, even an entire fleet of low-emission, sustainably-fueled motor vehicles would not reduce traffic accidents or solve the traffic congestion problems that plague many urban areas and lead to lost productivity, frustration, and a reduced quality of life for millions of U.S. citizens. For these reasons, some analysts have suggested that transportation systems should probably in most areas be based on a diversity of modes for different distances traveled, speeds, cargo capacity, and so on, as well as diversity in the basic fuel used if such diversity actually does result in reduced social costs and improved well-being (Delucchi et al., 2002; Litman, 2002; among others).

There are in fact a variety of factors that have contributed to the impetus to develop more efficient and lower-emission "alternative-fuel" vehicles (AFVs) in recent years. These factors include lowered emissions standards for motor vehicles, including "zero-emission vehicle" mandates in California, New York, Vermont, and Massachusetts; public concern about the various impacts of conventional petroleum-fueled motor vehicle use on human health and the environment; and the desire of automobile manufacturers to be perceived as responsible corporations and technological leaders. More specifically, primary issues of public concern related to motor vehicles have included the following, in addition to several other concerns (e.g., noise, visibility impacts, etc.):

- the persistent inability of some U.S. urban areas to achieve federal and state air quality standards, particularly in Southern California, the Northeast, and the Southwest;

- the potential climatic impacts of motor vehicle-related greenhouse gas (GHG) emissions;

- the overwhelming dependence of the transportation sector on petroleum; and

- the increasing share of oil imports relative to domestic production.

Of these, some debate continues over the potential future severity of the "climate change" problem, but there is a general consensus that GHGs produced by humans are building up in the atmosphere and that some climatic changes are taking place as a result (IPCC, 2001). As a result, most scientists agree that GHG emissions should be stabilized as soon as possible to avoid the threat of costly and potentially catastrophic problems in the future, but some politicians and others argue that future study is needed before major emission-reduction actions are taken.

As for the other issues, however, there is much less debate. It is not disputable that the human health effects of air pollution remain serious in many areas of the U.S., and particularly with recent geopolitical events few would argue the point that the high level of dependency of the U.S. on imported petroleum is a clear area of national concern. In fact, the U.S. Department of Energy (DOE) reports that over 55% of the petroleum used in the U.S. was imported in 2001, and forecasts that 68% will be imported by 2025 (EIA, 2002). These forecasts imply growing vulnerability to oil price shocks and supply disruptions, as well as balance of trade and international political issues. With tensions between the U.S. and Iraq, Libya, Syria, and several other nations in the Middle East reaching at least 50-year historical highs, largely due to the U.S. presence in the region to protect oil interests, there is now considerable attention being paid to the heavy use of petroleum in the U.S. transportation sector and the role of this dependence in the politics of the Middle East.

Partly as a response to these concerns, the issue of raising the fuel economy of new vehicles sold in the U.S. has been a particularly hotly contested area of political debate over the past few years. Some politicians and interest groups are advocating expanded domestic exploration, drilling, and production of oil on the supply side, and others arguing for demand side control measures such as raising Corporate Average Fuel Economy (CAFE) standards for vehicles. After several years of congressional "riders" that prohibited government studies on the safety and economic implications of changes to the CAFÉ standards were discounted in 2001, the National Research Council (NRC) completed a report that considered the potential for vehicle fuel economy improvements, and the potential costs of these improvements (NRC, 2002). The U.S. Congress has not yet directed the Department of Transportation (DOT) to examine in more detail the prospects for vehicle fuel economy improvement, as some expect it to based on the NRC report findings, but in the meantime DOT is apparently undertaking some CAFE program research activities on its own.

As a result of these concerns, and because automakers themselves are now seeking to reduce the fuel consumption and environmental impacts of their products, it is becoming increasingly clear that significant industrial change is underway in the global vehicle industry. Every automaker in the world, large and small, is now scrambling to stay abreast of the developments in the fields of lightweight materials, power electronics, battery and fuel cell systems, electric motors, ultracapacitors, and other technologies. Several of them have commercialized or plan to commercialize HEVs, with the apparent intent of developing FCVs as the next generation of vehicle technology to follow. The ultimate outcome of this period of technological innovation in the automobile industry is impossible to predict, but the confluence of innovation is enabling several new types of ultra-efficient and clean vehicle technology. The important questions are no longer whether these technologies will be produced and adopted, but rather at what pace, in which locations first, and in what exact forms of vehicle and associated refueling infrastructure design.

II. Hybrid-Electric Vehicles

The types of advanced vehicles being considered include battery-powered EVs (BEVs), HEVs, and FCVs, among others. BEVs are still of some interest due to their complete lack of tailpipe emissions and their relative simplicity, but the high cost and long recharging times of the large battery packs that these vehicles use remain a hindrance, along with the relatively short driving ranges that they offer. HEVs are a very promising option, with a few models already for sale in the U.S. and other countries, and sales exceeding the expectations of many industry analysts. Meanwhile, FCVs are coming on fast with intense development efforts and recent announcements of expansions to the initial demonstration and trial programs in the U.S., Japan, Germany, and Canada.

The Toyota Motor Company is leading the HEV market, most notably with the Prius sedan and Estima minivan vehicles. As shown in Table 1, in March of 2002 Toyota exceeded the 100,000 level of total cumulative HEVs sold, and based on the first quarter of 2003 appears on pace to see about 60,000 HEVs in 2002 (Automotive Intelligence News, 2002). Honda introduced the Civic Hybrid in 2002, and it too is selling well. In 2001, approximately 40,000 hybrid EVs were sold around the globe, with Toyota accounting for 90% of the market (Automotive Intelligence News, 2002).

Table 1: Cumulative Toyota Motor Corporation HEV Sales

	1997	**1998**	**1999**	**2000**	**2001**	**2002 (1st Qtr)**	**1997~2002 Total (up to Q1‘02)**
Prius	323	17,653	15,243	19,011	29,459	7,402	89,091
Estima Hybrid					5,886	5,840	11,726
Crown w/ mild hybrid system					1,574	520	2,094
Coaster Hybrid (bus)	9	3	12	15	9	8	56
Total by Year	332	17,656	15,255	19,026	36,928	13,770	102,967
Cumulative Total	332	17,988	33,243	52,269	89,197	102,967	

Source: Toyota Motor Corporation Estimates (Automotive Intelligence, 2002).

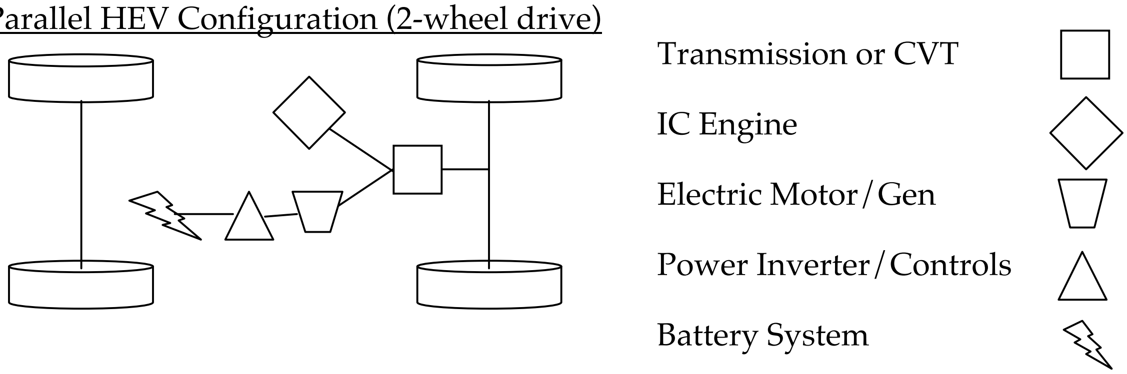
In this analysis, we focus on HEVs and the manufacturing, retail, and lifecycle costs of HEV designs that can improve the fuel economy of motor vehicles. We have previously analyzed the retail and lifecycle costs of BEVs in a project for the California Air Resources Board, an in a parallel effort we will be updating and refining our previous analyses of FCV costs (Delucchi, 1994; Lipman, 1999d).

There are in principle many different types of HEVs, as various drive-system configurations are possible and the drivetrain power can be divided between the internal-combustion engine (ICE) part and the electric motor/battery part in any proportion. Furthermore, some types of hybrid vehicles, known as "plug in" hybrids would have larger battery packs and a substantial "zero-emission vehicle range." In this analysis, we do not consider these "plug-in" hybrids but instead focus on the more conventional type of HEV that refuels only with gasoline, and that then uses extra engine power and/or regenerative braking to recharge the battery pack with a reversible motor/generator.

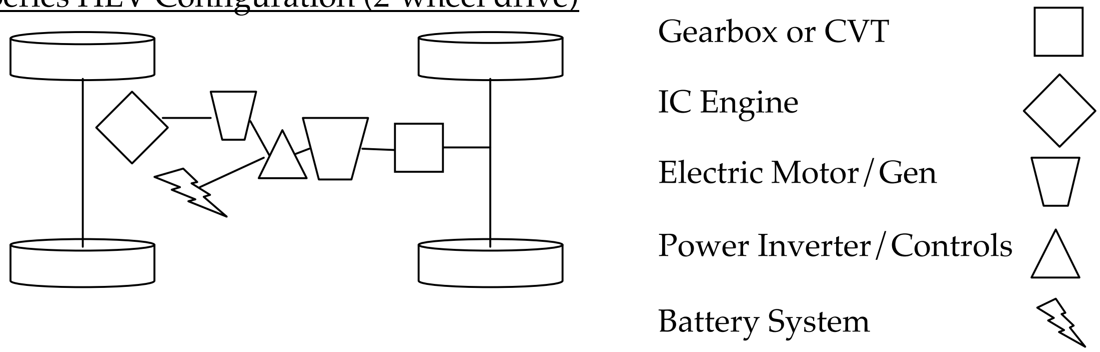
We also note that one emerging type of system, known "42-volt integrated-starter generator (ISG)" or "engine start/stop" systems is also being considered for use in vehicles. We do not consider these systems to be true hybrid vehicle systems because they have minimal ability "launch" the vehicle with electrical power and also have minimal regenerative braking capability due to the small size of the generator and battery pack. The main purpose of these systems is to allow the engine to shut off at idle, and in essence they represent a modest incremental change to conventional technology rather than being a genuine step toward true HEVs. We do not consider these systems here, with the exception of one set of "full" hybrid cases that also include an ISG system to more smoothly start up the engine after the vehicle has been launched with only the electric motor and is already in motion (see below for details).

The following figures graphically depict the design of "parallel" HEVs, in which both the ICE and electric motor can supply motive power to the drive wheels, and both two-wheel drive and four-wheel drive "series" HEVs in which the ICE acts only to operate a generator that recharges the vehicle battery pack, in essence as a "range extender" for a BEV. In this series configuration, the second motor/generator allows the battery to be recharged from the ICE, even when the primary traction motor is engaged.

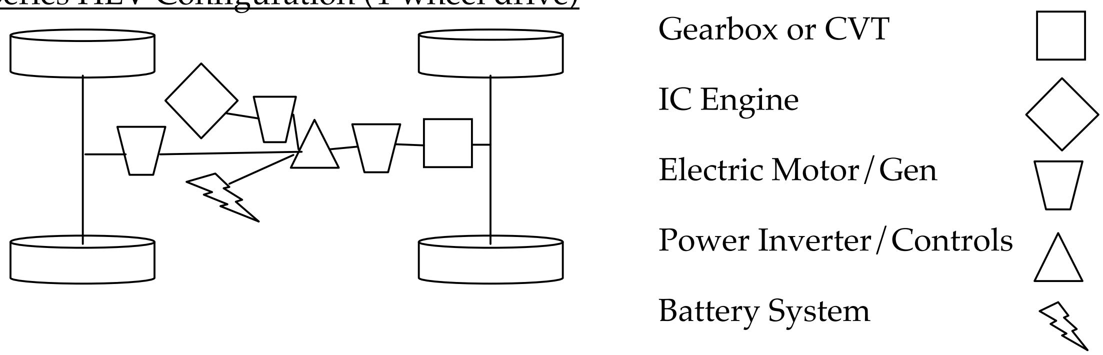
Parallel HEV Configuration (2-wheel drive)



Series HEV Configuration (2-wheel drive)



Series HEV Configuration (4-wheel drive)



In addition to the distinctions between HEVs made in the above diagrams, it is worth distinguishing more clearly between three primary types of HEVs. These three hybrid types are:

1) "mild" HEVs that also include regenerative braking and engine start/stop but that also use the electric motor in a parallel configuration to assist in powering the drive wheels when needed;

2) "full" HEVs that in addition to the above also have full electric launch capability, potential "ZEV range" and typically a higher percentage of system power from the electric motor part of the propulsion system; and

3) series or "range extender" HEVs that employ a full-sized electric motor (and only use the ICE through a generator to recharge the battery) in addition to including regenerative braking and significant "ZEV range." These vehicles may or may not be of the "plug-in" type, where the battery can also be recharged from an off-board electricity source.

In this analysis, we focus on HEVs of the parallel type, as these appear to be the most economical type of design. Series HEVs tend to be more expensive because they require a full-sized electric motor as well as an ICE and additional generator, and as a result interest in these designs has waned in recent years.

Previous Research on HEV Retail and Lifecycle Costs

Several studies have previously examined the potential manufacturing costs of HEVs compared with conventional vehicles, although few have simultaneously examined vehicle manufacturing costs, retail prices, and vehicle lifecycle costs in detail. Also, HEV cost studies have typically examined one or two vehicle types, rather than the five different vehicle body styles that we examine here. We are also unaware of any previous analysis that has linked a detailed high-volume HEV retail cost and lifecycle cost analysis with a detailed HEV performance analysis (e.g. based on the Advisor model) to this level of detail, although several other efforts have been made along these lines (EEA, 2002; Burke et al., 2002; Plotkin et al., 2001; Greene and DeCicco, 2000; Weiss et al., 2000; and Thomas, 1999). Other non-published, "internal" industry and government analyses have of course been conducted, some very detailed as pre-cursors to major investments in vehicle R&D and commercialization, but most of these studies are held proprietary and not accessible to the broader audience of industry practitioners, government agencies, interest groups, analysts and academic researchers, and the general public.

Efforts to compare the results of various HEV cost studies that have been performed in the past is complicated by the different vehicle types analyzed in these studies (and resulting difference in vehicle weight and drivetrain power) and varying other important assumptions. In a recent analysis, Santini et al. (2002a) have done a careful job of examining many of these studies in a comprehensive manner, attempting to account for key differences between the studies and analyzing them with a consistent metric.[1] The following table presents the key results of these various studies for the mid-sized vehicles that most of them consider,[2] as reported by Santini et. al (2002a) and including our addition of one additional recent study (Burke et al., 2002).

Most of these analyses yield results that are comparable, with the general exception that the Burke et al. (2002) and Weiss et al. (2000) studies estimate mild HEV price increments that are on the order of $1,500 to $1,700, versus about $3,000 in most other studies. Incremental prices of mid-sized "full" HEVs tend to be in the range of $3,400 to $4,800, with series HEVs with 20 to 60 miles of ZEV range having incremental prices of $7,000 to $10,000.[3] We discuss our results in the context of these previous results in our "Conclusions" section at the end of this report.

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[1] In an analysis of the importance of the cost-effectiveness metric used in analyzing HEV costs and fuel economy benefits, Santini et al. (2002b) argue that the best metric is the "e-Liter" method that uses the metric of liters of fuel saved / 10,000 km / $1,000 of incremental vehicle price. Santini et al. argue that other metrics can yield misleading inferences regarding the apparent increasing or decreasing cost-effectiveness with progressive vehicle improvement "steps." We therefore use this e-Liter metric for comparison purposes at the end of this report.

[2] Some include one or two other vehicle types as well, such as a smaller passenger car and/or SUV.

[3] These incremental prices are referred to as "HEV Price Effects" in this report.

Table 2: Results of Major HEV Cost Studies – Estimated Vehicle MSRP Values and HEV Price Effect for Mid-Sized Vehicles

	ANL	ANL	ANL	EEA*	EF	EPRI Base	EPRI Low	MIT	NRC	UCD
Base ICEV Price	$21,200	$22,500	$25,100		$19,827	$18,984	$18,984	$19,400		
ICEV w/42V ISG Price				($1,760)	$20,327 ($500)				($280-630)	
Mild HEV Price	$24,150 ($2,950)	$25,710 ($3,210)	$28,200 ($3,100)	($2,780)	$23,057 ($3,230)			$21,100 ($1,700)		($1,441)
Full HEV Price	$24,610 ($3,410)	$26,520 ($4,020)	$29,770 ($4,670)	($3,980)	$24,624 ($4,797)	$23,042 ($4,058)	$21,268 ($2,284)			($3,371)
HEV20 Price		$29,740 ($7,240)	$33,070 ($7,970)			$24,966 ($6,002)				
HEV60 Price						$29,523 ($10,539)	$25,881 ($6,897)			
Assumed Performance	12 sec. 0-60	10 sec. 0-60	8 sec. 0-60	12 sec. 0-60	10 sec. 0-60	9 sec. 0-60	9 sec. 0-60	10 sec. 0-60	Not specified	Not specified

Notes: The first value shown is the full MSRP, and the value shown below in parentheses is the HEV price effect. All estimates are from Santini et al., 2002a, except for EEA, NRC, and UCD. ANL is Plotkin et al., 2001; EEA is Energy and Environmental Analysis Inc., 2002; EF is An et al., 2001; EPRI is Graham et al., 2001; HEV20 is an HEV with 20 miles of ZEV range; HEV60 is an HEV with 60 miles of ZEV range, MIT is Weiss et al., 2000; MSRP is manufacturers suggested retail price; NRC is National Research Council, 2002; UCD is Burke et al., 2002.
*For EEA, "Mild HEV" is a 150V system and "Full HEV" is a 300V system.

Linked HEV Retail/Lifecycle Cost and Performance Modeling

For purposes of this analysis, we have updated and made major modifications to a detailed motor vehicle retail and lifecycle cost spreadsheet model that we have previously used to analyze the costs of various types of conventional vehicles, electric-drive vehicles, and other AFVs (Delucchi et al., 2001; Delucchi and Lipman, 2002). Although in the past we have used this model to roughly approximate the potential lifecycle costs of HEVs relative to conventional vehicles, we have never before analyzed HEVs in detail. In order to do that here, we made several structural changes to the spreadsheet model. These allow for the analysis of vehicles with combined ICE and electric drivetrain components, whereas before only one type of drivetrain could be included in a specific vehicle. We have also added three additional conventional vehicles types (large pickup, minivan, and sport-utility vehicle or SUV) to the compact and mid-sized vehicles that we have previously analyzed.

However, we are still in the process of developing the detailed HEV energy use analysis capabilities of the spreadsheet model, especially for these newly added vehicle types. The model currently estimates HEV and other AFV vehicle retail prices (along with manufacturing costs) and vehicle lifecycle costs, but the detailed vehicle energy-use analysis for HEVs has not yet been fully completed. Therefore, for this analysis we are linking the detailed cost-analysis spreadsheet model with HEV performance analysis runs conducted by our colleagues (Friedman and An, 2003) using the well-known and validated Advisor HEV performance model that was developed by the National Renewable Energy Laboratory along with several contractors (Markel et al., 2002). Using the results of the Friedman and An analysis of the design and performance of various HEV designs, we have then calibrated the design of the vehicle in the spreadsheet by making simple adjustments to a few vehicle parameters as we exercised the spreadsheet model. In essence, by iteratively adjusting the specific characteristics shown below we were able to reproduce the same vehicle characteristics within the model and then used our costing procedure to estimate the final vehicle manufacturing cost, MSRP, and fully-loaded vehicle price estimates as well as the lifecycle cost and gasoline breakeven price estimates.

Some of the major parameters specified for this analysis include:

- Vehicle type (compact, mid-sized car, large pickup, minivan, SUV)

- Vehicle drivetrain efficiency, where efficiency is defined as "useful work out divided by energy input" (0-1.0);

- ICE power in kW and displacement (liters of volume and number of cylinders);

- Vehicle mass (including estimated mass reduction for moderate and advanced improvement packages);

- Battery energy capacity in kWh (power in kW is sized to meet motor power requirement in absence of additional generator, and battery mass is determined from modeled "Ragone-plot" type tradeoff in battery power and energy density with cell size);

- Battery and vehicle lifetime assumptions (7.5 year battery life and 15 year vehicle life in base case);

- Additional "HEV price effect" of high-efficiency engine;

- Additional "HEV price effect" vehicle mass and drag road-load reduction; and

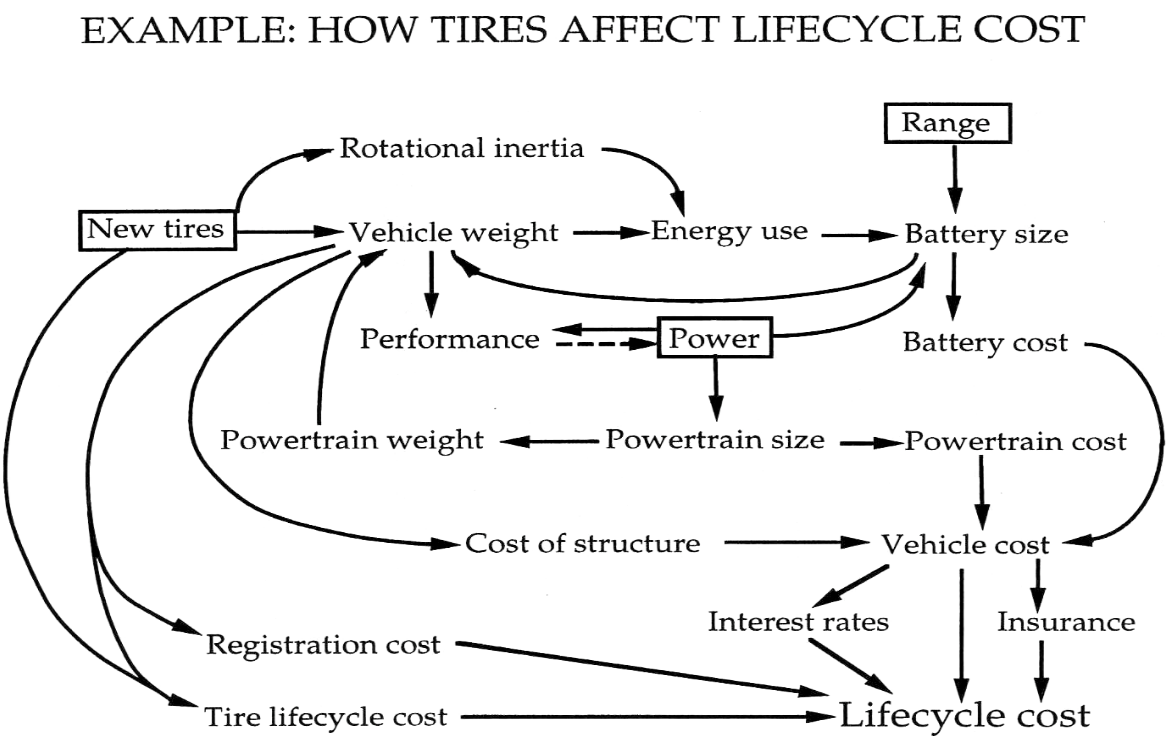
- Additional "HEV price effect" of ISG system (if used);

These performance and cost estimates, along with other items such as vehicle 0-60 acceleration times, drag coefficients, frontal area values, etc., are fully presented in Friedman and An (2003) – which should be considered a "companion" report to this one for those interested in all of the performance and cost analysis details -- with only the values most relevant to this cost study presented in Table 4 (see below) and in the detailed tables in Appendix A.

HEV Retail and Lifecycle Cost Model Diagram

The following diagram graphically depicts the general nature of the Lotus 123 spreadsheet model used for the analysis of HEV manufacturing, retail, and lifecycle costs. In this example, the characteristics of the vehicle tires are modified, and this then creates several small changes in the design of the vehicle as model runs are performed iteratively and the model converges on a "new solution." This illustrates some of the "circularity" in the spreadsheet model, and the manner in which changes in component parameters can produce compounded or decompounded effects on the mass, cost, and drivetrain power and torque requirements of the vehicle being analyzed (see Delucchi et al., 2001 for more details).

Figure 1: HEV Retail and Lifecycle Cost Model Diagram



Source: Delucchi et al., 2001

HEV Cases Examined and Major Accompanying Assumptions

The following table shows the HEV vehicle classes and degrees of hybridization considered, as well as the "codes" used to distinguish the cases that are used throughout the remainder of the report. In addition to these 25 example vehicle designs, we also include analysis of two of the three HEVs currently on sale in the U.S., the Toyota Prius and Honda Civic Hybrid.

Table 3: HEV Types and Improvement/Hybridization Levels Considered

Vehicle Type	Moderate Package/ Mild Hybrid (MM)	Moderate Package/ Full Hybrid (MF)	Advanced Package/ Mild Hybrid (AM)	Advanced Package/ Full Hybrid 1 (AF1)	Advanced Package/ Full Hybrid 2 (AF2)
Cavalier / Compact	Cavalier MM	Cavalier MF	Cavalier AM	Cavalier AF1	Cavalier AF2
Taurus / Mid-Sized	Taurus MM	Taurus MF	Taurus AM	Taurus AF1	Taurus AF2
Silverado / Lg. Pickup	Silverado MM	Silverado MF	Silverado AM	Silverado AF1	Silverado AF2
Caravan / Minivan	Caravan MM	Caravan MF	Caravan AM	Caravan AF1	Caravan AF2
Explorer / SUV	Explorer MM	Explorer MF	Explorer AM	Explorer AF1	Explorer AF2

In general, the "moderate package of improvements" includes modest vehicle weight and drag reduction measures, and the inclusion of variable-valve-timing and lift-electronic-control (VTEC) combustion engine technology. The vehicle weight reductions range from 0% (compact), and 10% (mid-sized), to 20% (large pickup, minivan, and SUV), and the vehicle coefficient of drag reductions are 10% in all cases. The "advanced package of improvements" includes more dramatic vehicle weight reductions, vehicle rolling-resistance changes, and transmission modifications, as well as the inclusion of gasoline direct-injection (GDI) engine technology. The vehicle weight reduction levels for the advanced cases range from 10% (compact), and 20% (mid-sized), to 33% (large pickup, minivan, and SUV). All of these improvements are relative to the conventional ICE vehicle base cases.

The degrees of hybridization – "mild" and "full" – generally refer to the relative division of drivetrain power between the combustion engine and the electric motor, but the "full" hybrids are also characterized by electric launch capability (and thus some potential "ZEV range"). In the mild cases, the electric motor supplies about 15% of the total drivetrain power. In the "AF1" cases, the electric motor supplies about 40% of the total power, and in the "AF2" cases the electric motor supplies about 25% of the total drivetrain power. The larger motors in the AF1 and AF2 cases are supported by higher power motor controller/inverters, and also larger and more powerful battery packs.

We note here that for purposes of this analysis, we have chosen to apply these "packages of improvement" in combination with the HEV technology, to compare how future HEVs might compare to example baseline conventional vehicles. We acknowledge that these improvements could also yield fuel economy benefits when used with conventional vehicle technology, in effect as "modified baseline vehicles," and that comparison of these somewhat improved conventional vehicles with these various HEVs would be interesting. We hope to consider an expand array of both conventional and electric-drive (e.g. fuel cell powered) vehicles in a subsequent analysis, including these more advanced conventional vehicles.

Table 4, below, shows some of the primary characteristics of the vehicles analyzed. Additional details of vehicle characteristics can be found in the detailed results tables in Appendix A and in the Friedman and An (2003) "companion report."

Table 4: Basic Characteristics of Baseline Vehicles and HEVs

Vehicle Type	Vehicle Test Wgt. (kg)	ICE Power (kW)	Electric Motor Power (kW)	Total Power (kW)	CAFE Fuel Economy (mpg)	"Real World" Fuel Econ. (mpg)
Base Cavalier	1420	85.8	N/A	85.8	30.8	25.3
Base Taurus	1648	115.6	N/A	115.6	26.2	21.5
Base Silverado	2159	201.3	N/A	201.3	19.6	16.1
Base Caravan	2045	134.2	N/A	134.2	22.3	18.3
Base Explorer	2045	156.6	N/A	156.6	19.9	16.3
Cavalier MM	1393	73.7	13.0	86.7	48.6	39.9
Taurus MM	1492	90.7	16.0	106.7	44.7	36.7
Silverado MM	1792	153.0	27.0	180.0	31.0	25.4
Caravan MM	1686	107.7	19.0	126.7	38.4	31.5
Explorer MM	1689	124.7	22.0	146.7	33.4	27.4
Cavalier MF	1459	54.0	36.0	90.0	57.6	47.2
Taurus MF	1572	66.0	44.0	110.0	55.6	45.6
Silverado MF	1933	112.5	75.0	187.5	38.7	31.7
Caravan MF	1764	75.0	50.0	125.0	47.0	38.5
Explorer MF	1795	90.0	60.0	150.0	39.9	32.7
Cavalier AM	1266	62.3	11.0	73.3	58.7	48.1
Taurus AM	1313	73.7	13.0	86.7	54.4	36.7
Silverado AM	1460	113.3	20.0	133.3	40.2	33
Caravan AM	1386	79.3	14.0	93.3	49.1	40.3
Explorer AM	1395	96.3	17.0	113.3	42.2	34.6
Cavalier AF1	1294	45.0	30.0	75.0	69.6	57.1
Taurus AF1	1356	55.5	37.0	92.5	68.1	55.8
Silverado AF1	1517	82.5	55.0	137.5	49.9	40.9
Caravan AF1	1427	58.5	39.0	97.5	59.0	48.4
Explorer AF1	1444	70.5	47.0	117.5	50.2	41.2
Cavalier AF2	1278	57.0	19.0	76.0	67.3	55.2
Taurus AF2	1325	66.0	22.0	88.0	66.3	54.4
Silverado AF2	1480	102.0	34.0	136.0	48.8	40.0
Caravan AF2	1400	72.0	24.0	96.0	57.6	47.2
Explorer AF2	1412	87.0	29.0	116.0	49.3	40.4

Note: "Real world" fuel economy is a corrected, more realistic set of fuel-economy estimates for typical driving. The correction factor used is an ~18% reduction in fuel economy (see Friedman and An, 2003, for details).

Vehicle Chassis and Frame or "Glider" Costs

The vehicle cost spreadsheet model includes a "bottom-up" type of cost modeling approach that uses a breakdown of approximately 30 parts groups for the vehicle, and then estimates the manufacturing cost of each parts group based on its material content, material cost, labor cost, and overhead rate.

For this analysis, we have updated our previous vehicle cost estimates for the compact and mid-sized vehicles, and we have added estimates for the other vehicles, based on a new set of detailed vehicle manufacturing cost data that we have obtained from IBIS Associates. We have used these data primarily to add the SUV and pickup truck cases to the analysis, as well as to update our labor wage rates and some of our parts-group cost overhead rates. After examining these IBIS data, we now assume a labor wage rate of $18.50 per hour in a base year of 1998, and we assume that the wage increases 2.5% per year, an approximate cost of living increase (see Delucchi et al, 2001, for more details regarding labor wage rates and other basic model assumptions).

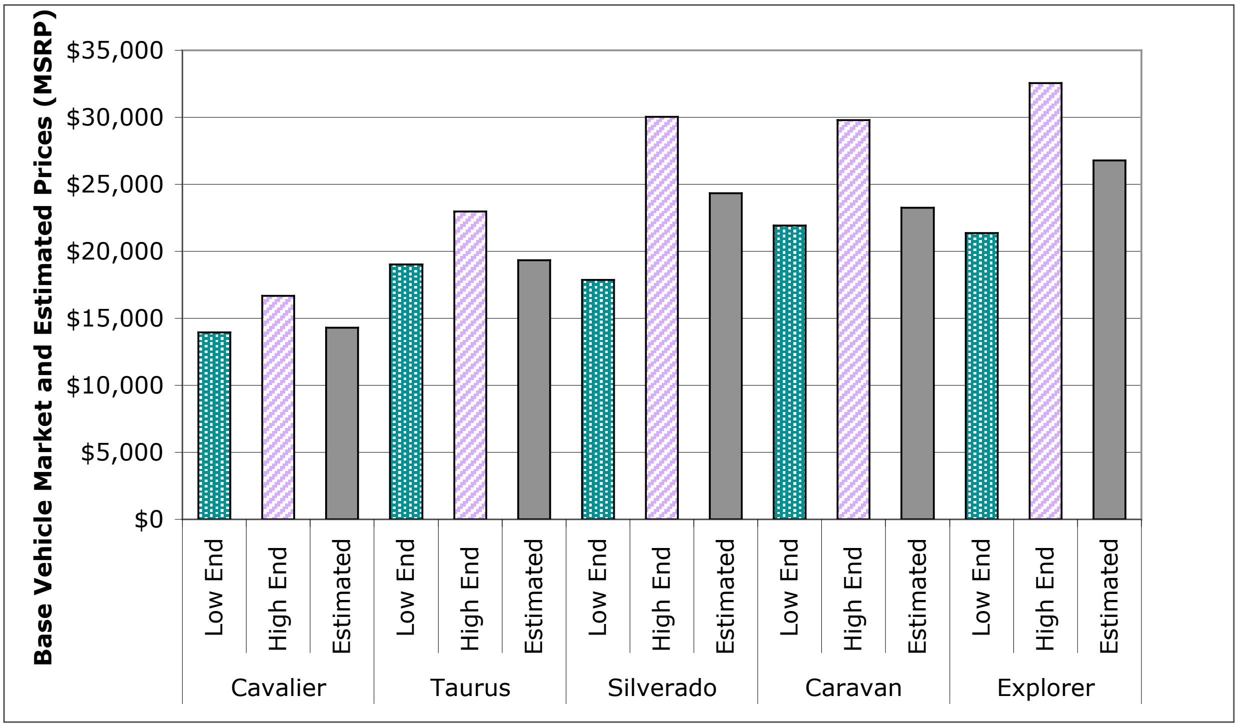
Because of the nature of the new data that we have obtained, we consider the added SUV case to be robust (along with the compact and mid-sized vehicle cases) because the vehicle that is the basis for the cost data closely matches the vehicle type that we are assuming from a performance standpoint. With regard to the minivan and pickup truck cases, the cost estimates for these baseline vehicles are somewhat more uncertain because we have estimated the costs of some of the parts groups for these cases based on analysis of the same parts groups in similar vehicles (e.g. the SUV for the large pickup and the mid-sized car for the minivan) and have therefore not analyzed them in the same level of detail as the compact, mid-sized, and SUV types.

In future work, we plan to further refine this analysis of the basic costs of the body-in-white, running frame, and additional basic components of the various vehicles, including detailed analysis of vehicle weight and drag reduction options. We will do this in particular for the compact and mid-sized vehicles (because our older cost estimates are getting out of date) and for the large pickup and minivan that we have estimated for this analysis. We note, however, that the MSRP values that we estimate for the baseline vehicles in this study do closely match the model year 2000 MSRP values for the actual vehicles that they are based upon, and that provides confidence that our estimates for the minivan and large pickup truck are reasonable. We expect that any relatively minor changes that we in the future make to these baseline vehicle cost estimates will be unlikely to significantly affect the overall HEV costs and patterns of costs that we have estimated here, but some minor revisions are likely in the future as we continue to update our ongoing work in this area.

Vehicle MSRP Plus Destination Charge Values

For purposes of this analysis, we examine vehicles in the five body style categories that fall approximately in the middle of the range of typical models for each vehicle type. Figure 1 shows the ranges of MSRP values for each of the five vehicle types that we examine here (based on recent market data), as well as the values that we calculate in the vehicle cost model for the "base" ICE vehicle that we use for purposes of comparison. As shown in the figure, the values that we calculate fall approximately in the middle of the typical range for each vehicle type.

Figure 1: Base Vehicle "Low End" and "High End" Market and Estimated MSRP Values



Source: For low-end and high-end market values, Automotive News (2002).

With regard to these base ICEV MSRP estimates, note that we are generally estimating the costs and prices of "mid-range" vehicles, with the exception of the Taurus and Caravan where our estimates fall closer to the lower end of the range. We could in principle analyze higher-end or lower-end vehicles of each type, but for purposes of this study we have attempted to examine mid-range vehicles. We also note that in making these comparisons, one must be careful because sometimes "vehicle price" refers to the MSRP value, and in other cases it refers to the MSRP plus destination (shipping) charges, plus in some cases consumer taxes. We use the following definitions for the vehicle costs and prices that we estimate:

- Vehicle manufacturing cost = function of material costs, labor costs, material usage, labor hours, and labor overhead;

- Dealer invoice = manufacturing cost, plus division costs, plus corporate costs;

- MSRP = dealer invoice plus dealer costs;

- Retail price to consumer = MSRP plus shipping cost plus sales tax

Hybrid Electric Vehicle Component Costs

HEVs incorporate several new technologies relative to conventional vehicles. These include most notably:

- 10-50 kW high torque and efficiency (usually brushless permanent magnet or "BPM") electric motors;
- high power-density and long cycle-life batteries, with cell sizes ranging from approximately 3 Amp hours (Ah) to 50 Ah (or ultracapacitor system, flywheel, or other peak power device);
- ICE technologies such as VTEC and GDI that lead to high torque/power density, high efficiency, and lower emissions;
- regenerative-braking system(s) for deceleration energy recapture to battery;
- HEV system controls (32-bit or more) and electric motor controller(s) and power inverter;
- a DC/DC converter to power auxiliaries (versus using a separate e.g. 42-volt battery system);
- a secondary motor/generator to allow simultaneous electric motor power-to-wheels and battery recharge from excess ICE power (for series HEVs or "split power" HEVs that are essentially parallel HEVs but that use ICE power to simultaneously propel the vehicle and to operate a generator, as in the Toyota Prius) ;
- high-efficiency auxiliary systems;
- vehicle weight, drag, and rolling-resistance reduction measures; and
- drive-by-wire and brake-by-wire systems ("drive-x-wire").

The exact details of which and what type of the above systems are included in a particular vehicle design can vary greatly, and many different strategies are possible for both delivering power to the wheels and providing additional energy for auxiliary and control systems.

For purposes of this analysis, we assume the use of brushless permanent magnet (BPM) electric motors based on neodymium-iron-boron magnet materials, advanced nickel-metal hydride (NiMH) batteries, VTEC ICE technology (moderate package cases) and GDI ICE technology (advanced cases), regenerative braking, essential system controls and power inversion, varying assumptions about power to auxiliaries (see below), no secondary motor/generator (except in the "Toyota Prius" case), more efficient auxiliary systems, and no novel drive-x-wire systems. Following is a brief summary of the key assumptions made for the costs of these systems in future high-volume production, in the 2010-2015 timeframe.

Electric Motors and Motor Controller/Inverters

With regard to the costs of electric motors for HEVs, we have recently updated our ongoing analysis of the costs of electric-drive vehicle motors and controller/inverters with the assistance of UQM Technologies, Inc. (UQM) in Golden, Colorado. These estimates are not dramatically different than we have reported previously (Lipman, 1999a), but costs and expectations of future costs have declined somewhat in recent years. Table 5, below, shows the cost estimates provided to us by UQM, along with the mass of each component.

Table 5: Key Features of Brushless Permanent Magnet Motors and Controllers

Component	Rating	OEM Cost with 200K/yr Order	Mass
HEV Motors			
MPM30	30 kW 140 Nm peak	$320	29 kg
MPM50	53 kW 240 Nm peak	$395	40 kg
MPM80	80-85 kW 380 Nm peak	$445	50 kg
High-Torque and Power Motors			
SR286 (PowerPhase 100)	110 kW 550 Nm peak	$1,425	86 kg
INTETS System (includes integrated inverter/controller)	75 kW 1,700 Nm peak	$1,970	74 kg
Controller/Inverter			
CD40-400L	270-336 V Nom battery input 17 W standby power	$775	15.9 kg

Source: Component data from UQM company literature; cost estimates from McCanse, 2002.
OEM is "original equipment manufacturer."

Based on these cost estimates, we have developed logarithmic cost functions for use in the spreadsheet model in order to estimate motor and controller/inverter costs as a function of peak motor power. For controller/inverters, we have revised our previous cost function (that estimates controller/inverter costs as a function of peak system power), based on the new data shown in Table 5 and an examination of the costs of insulated-gate bipolar transistor (IGBT) power switches. These IGBT devices are the heart of the power inverter part of the motor controller, and the main sub-component set that scales with variations in controller/inverter power.

For high-volume production of 200,000 units per year, these functions for motor and controller/inverter costs to the automotive original equipment manufacturer

(OEM) are as follows:[4]

HEV BPM Motors (30-80 kW):

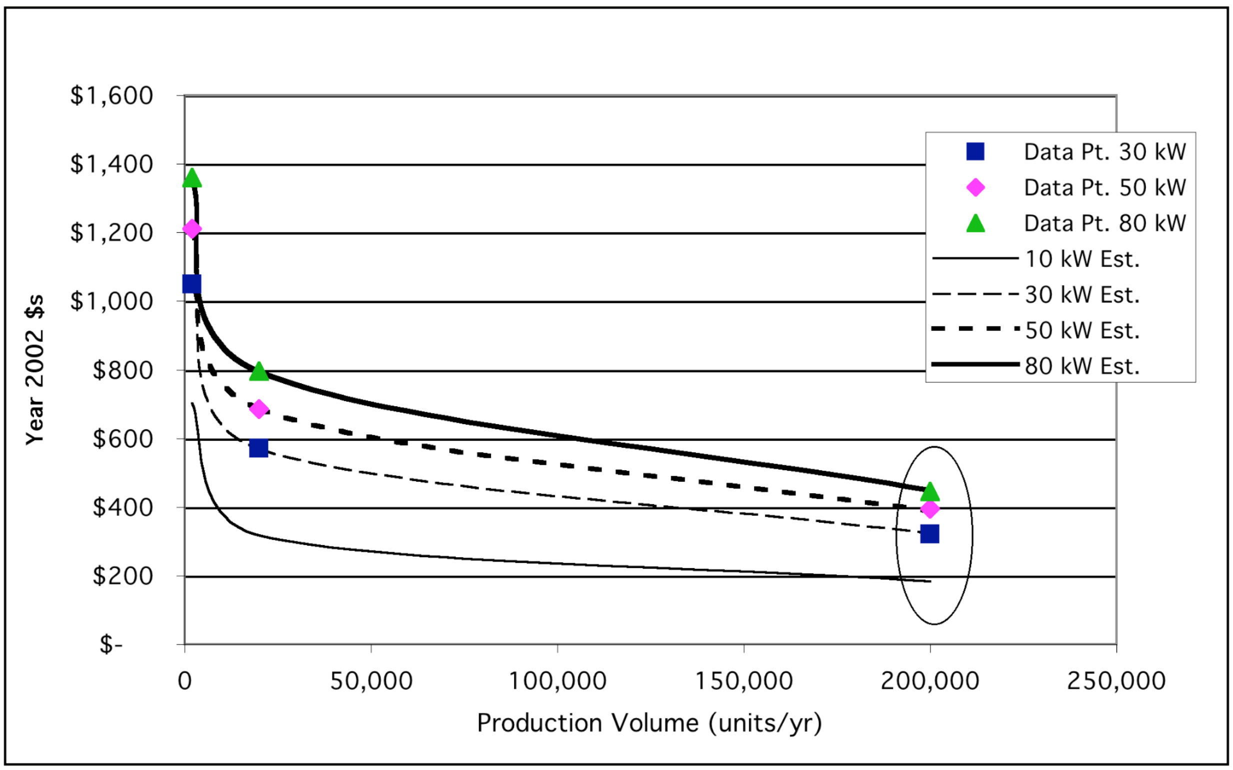
OEM Motor Cost ($s) = -111.3 + (127.7 * Ln (kW-peak))

Motor Controller/Inverters (10-100 kW):

OEM Controller/Inverter Cost ($s) = 480 + (2.95 * (kW-peak))

Figure 2, below, presents the electric motor cost function shown above as applied to example motors in the size range from 10 kW to 80 kW. As shown in the figure, the function closely approximates the cost data for production of 200,000 units per year for the 30-80 kW motors. We also extend this function to estimate costs to the OEM of motors as small as 10 kW, as it produces results that we (along with an industry expert that we consulted) believe to be reasonable. With this cost function, the cost estimate for a 10-kW motor is about 60% of the cost of a 30-kW motor, at the 200,000 per year production volume.

Figure 2: BPM Electric Motor Cost Data and Estimates By Power Rating and Production Volume



Source: Cost data from McCanse, 2002.

[4] We define the OEM cost of a component as the full selling price of the component manufacturer to the automobile maker plant gate, or the equivalent fully burdened cost if the automaker makes the component itself.

In addition to these basic motor costs, we include miscellaneous bracket and cable costs of $1.50 per peak-kW. We also note that based on the estimates shown in the figure for lower production volumes, we also have developed motor cost functions for low volume production (2,000 units per year) and medium volume of production (20,000 units per year), as well as the high production volume estimates that we use for this analysis (200,000 units per year). Finally, HEVs with onboard charging systems also include the costs of these systems, but this is not applicable to any of the HEVs that we analyze here.

HEV Batteries

With regard to the costs of the NiMH battery that we assume for this analysis, we rely heavily on an extensive analysis that we previously conducted on the costs of these batteries in various production volumes, generations of technological advancement, and cell (Ah) capacity. In this previous analysis, we combined detailed technical modeling of battery performance to arrive at the materials types and quantities needed to produce a specific battery design (Burke, 1999) and then combined this with a detailed cost analysis that we performed in conjunction with industry experts (Lipman, 1999b).

For this forward-looking analysis for HEV costs in the 2010-2015 timeframe, we use the most advanced generation of battery that we examined – the "Gen4" battery design that included some extrapolations of progress in battery design and development when we performed this work in 1998-1999. Based on examinations of company literature (Texaco Ovonic, 2002), we believe that batteries with approximately this "Gen4" level of performance are now nearing commercialization, and it is likely that at least somewhat better designs will be available by 2010. We thus are confident that our NiMH battery performance specifications are reasonable for the timeframe considered in this analysis, with regard to the basic power and energy density characteristics of the battery (see below discussion of battery cycle life). We further suspect that our estimates are "on the conservative side" with regard to costs, again because we do not feel that the HEV battery designs that we analyzed in Lipman (1999b) are as forward-looking as this study generally is, with specific regard to slow but continuous improvements in HEV battery technology that we expect over the next several years. We suspect that the HEV battery technology that we saw being developed three years ago in visits with industry research facilities is now commercial, and that some further improvements in both NiMH and Li-ion technology are still possible. However we say this with the caveat that the industry is also attempting to drive down costs, and that it is difficult to achieve this with simultaneous *improvements* in technology (rather than merely maintaining performance while reducing costs).

In order to estimate the manufacturing costs and OEM costs of NiMH batteries for HEVs, we develop reference battery cost estimates, in terms of $ per kg of battery, based on Lipman (1999b). We then develop a battery cost formula with the coefficient "K" to adjust these reference costs. Essentially, the "K" coefficient in the battery-cost equation determines the "spread" of the $ per kg values for a given range of Wh per kg battery designs, and the smaller the coefficient the wider the spread of $ per kg values for a given range of Wh per kg battery designs (see Delucchi et al., 2001 for further details of the derivation of these estimates and for similar estimates for other battery types for HEVs, BEVs, and FCVs).

The general battery cost functions, developed in Delucchi et al. (2001) and used to estimate the $ per kg costs of NiMH for the HEVs here, are as follows:

$$MCTB = max\left\{MCC, MCC_{MIN}\right\} \cdot \frac{WTBM}{2.205} + BAUX$$

$$MCC = MCC^* - \frac{EDTB_{C/3} - EDTB_{C/3}^*}{K_{BM}} \cdot ln\left[EDTB_{C/3}\right]$$

Where:

MCTB = the manufacturing cost of the complete battery system ($; selling price from the battery OEM to the automaker, including distribution charges)
MCC = the estimated OEM cost of manufacturing a battery module (OEM selling price) per kg ($/kg)
MCC_{MIN} = the minimum allowable manufacturing cost, as a bound on the MCC function ($/kg)
WTBM = the weight of the traction battery modules (lb)
2.205 = lbs/kg
BAUX = the cost of the battery auxiliaries: tray, straps, bus bar, terminal interconnects, electrical harness, and thermal management system ($)
MCC* = the reference OEM manufacturing cost (selling price) per kg, for batteries of the reference specific energy ($/kg; discussed below)
$EDTB_{C/3}$ = the specific energy of the new battery (Wh/kg)
$EDTB_{C/3}^*$ = the reference specific energy of the new battery (Wh/kg)
K_{BM} = coefficient

For the "Gen4" NiMH batteries assumed for the HEVs analyzed here, the estimated value of MCC* (the reference manufacturing cost) is 17.69 for the high-volume production case, the estimated value of $EDTB_{C/3}$ (reference energy density) is 75 Wh per kg, and the value of K_{BM} is 15 (again, please see Delucchi et al. 2001 for details of the derivation of these estimates). Also note that for purposes of this analysis, we adopt the 100,000 packs per year volume figures under the assumption that most economies of scale have been captured at this level, and that costs are similar for 200,000 packs per year.

Our estimate of MCC* is based on the NiMH battery OEM cost estimates of Lipman (1999b), shown in Table 6

Table 6: OEM Cost Estimates for Gen4 NiMH BEV/HEV Batteries

Generation and Cell Size	Low Cost Case	High Cost Case	Average
Generation 4 @ 100,000/yr:			
20 Ah	$211.29/kWh ($21.13/kg)	$240.23/kWh ($24.02/kg)	$225.76/kWh ($22.58/kg)
60 Ah	$199.23/kWh ($20.79/kg)	$225.66/kWh ($23.55/kg)	$212.45/kWh ($22.17/kg)
100 Ah	$154.62/kWh ($16.52/kg)	$176.39/kWh ($18.85/kg)	$165.51/kWh ($17.69/kg)
150 Ah	$133.94/kWh ($15.16/kg)	$153.63/kWh ($17.39/kg)	$143.79/kWh ($16.28/kg)

Note: In terms of $/kWh, the values shown in the detailed results tables for the full retail price of the HEV battery to the consumer are much higher than these values due to the compounding effects of three variables: 1) the smaller cell sizes for the HEVs analyzed in this study and the resulting higher power density but lower energy density (in our model, specific power and specific energy are traded off, and the HEV batteries have higher specific power but lower specific energy than do EV batteries); 2) the addition of battery tray, wiring, and auxiliaries in the final estimates; and 3) the mark-up from the cost of the battery to the OEM, to the final retail price for the consumer (roughly a factor of two).

With regard to the estimates shown in Table 6, we note here that they were primarily developed to assess the costs of relatively large capacity NiMH cells used for battery EVs (in the 80 to 100 Ah range). While we did purposely examine the costs of smaller cells, down to 10 Ah, as part of the Lipman (1999b) study due to our interest in HEV and FCV batteries, we do not have the same level of confidence in our results for the much smaller cells, that we are in some cases considering here, than we do for the larger EV battery cells. As noted above, we consider our estimates somewhat conservative for HEV batteries because of additional options for optimizing the designs for these small cells that we did not fully consider. We also have seen some other forecasts internal to industry suppliers that suggest that future NiMH HEV packs could cost somewhat less than we estimate. As a result, we include example sensitivity analysis on this important parameter (along with battery cycle life and replacement cost) in the "Sensitivity Analysis" section of this report.

High Power-Density and High-Efficiency Combustion Engines

With regard to the costs of high-performance ICEs, estimates for the incremental manufacturing costs of these engines compared to similar more conventional engines are typically in the range of $200 to $300 per engine, depending on the specific engine type (VTEC, GDI, etc.) and size, and including double camshaft-phasing, often in the form of dual-overhead cam (DOHC), and cylinder deactivation (Duesman, 2002; NRC, 2001; DeCicco et al., 2001). For VTEC, the engine costs also depend on the type of valve activation such as mechanical or electro-mechanical, and whether or not all of the engine valves (both intake and exhaust) are included. These incremental manufacturing costs then translate to approximately $350 to $600 at the retail level, depending on the vehicle cost accounting structure and markup-levels used.

For this analysis, we adopt the cost of engine improvement estimates developed by DeCicco et. al (2001), who considered a similar set of potential HEV types that we consider here. Table 7, in the following section, presents the retail price increases that we assumed for each case, along with the DeCicco et al. estimated costs of vehicle weight and drag reduction that we also adopt here (see below).

We incorporate these additional costs of high-efficiency engines into the spreadsheet model by altering the cost per pound of the engine (which is then multiplied by engine weight to arrive at the overall manufacturing cost of the engine) so that the retail price increase of the vehicle is as shown in Table 7, compared to a vehicle with the same size conventional ICE.

Additional HEV Costs

In addition to the component costs discussed above, additional costs associated with the HEVs considered include the costs of vehicle weight and drag reduction, costs of regenerative braking systems, and costs of other specialized HEV equipment including ISG and high-efficiency auxiliary systems.

First, with regard to costs of vehicle weight and drag reduction, these costs are difficult to estimate because vehicle weight reduction can be accomplished various ways and with different materials (high-strength steel, aluminum, composites, etc.), and vehicle drag reduction is primarily an design and engineering cost that may only entail small actual changes in vehicle materials and costs (such as covered rear wheel wells). We have explored these topics to considerable extent in the past, in the context of analysis of battery EVs, based on analysis by two other organizations: Energy and Environmental Associates (along with the Office of Technology Assessment prior to 1995) and IBIS Associates. However, in these previous analyses we considered only Escort/compact and Taurus/mid-sized type vehicles, and not the fuller array of vehicle types that we consider here. We plan a detailed analysis of vehicle weight and drag reduction costs in the future for all of these vehicle types, but for purposes of this analysis we adopt the estimates in DeCicco et al. (2001), again because they match the vehicle characteristics and performance specifications of the vehicles here to a close degree. We note here that we believe these estimates to be reasonable, but also potentially optimistic because they assume that the first 15% of vehicle weight reduction comes at no net cost from the use of high-strength steel, and that there is then a cost penalty for weight reduction beyond that point. This is why there is no cost penalty for some of the "moderate package" cases shown in Table 7.

Table 7: Retail Price Increases from Vehicle Improvements (Year 2000 $s)

Moderate Package	Escort/ Compact	Taurus/ Mid-Sized	Silverado/ Lg. Pickup	Caravan/ Minivan	Explorer/ SUV
Mass reduction	0	0	223	210	198
Drag reduction	174	176	182	180	178
Efficient VTEC engine	270	360	360	360	360
Advanced Package	**Escort/ Compact**	**Taurus/ Mid-Sized**	**Silverado/ Lg. Pickup**	**Caravan/ Minivan**	**Explorer/ SUV**
Mass reduction	0	166	801	756	1,080
Drag reduction	175	176	180	178	178
Efficient GDI engine	450	450	560	450	450
Integrated starter-generator[1]	300	347	537	379	458

Source: DeCicco et al. (2001) for mass and drag reduction and engine improvements, our estimates for ISG systems based on NAS (2001) and DeCicco et al. (2001).

[1]Used in "advanced full 2" (AF2) HEV cases only and based on engine size.

In addition to the vehicle mass and drag reduction and engine improvement measures that we assume for all HEV cases, we also include an integrated-starter generator (ISG) system for our "Advanced / Full 2" HEV cases. We include this for these cases because like the other "Full" HEV cases we have assumed electric-motor-only start for these vehicles, but we do not believe that the electric motors used in these designs are sufficiently large to act as starter motors in a smooth fashion and to eliminate the need for a separate starter-generator. We assume that such ISG systems are not necessary in the "Full 1" HEV cases, although we acknowledge that this is a point of some debate.[5] In this case, we assume that the use of such 42-volt ISG systems will be routine in the 2010-2015 timeframe, and we adopt the high-volume retail price increases for these systems shown in the table.

HEVs, like BEVs, would also typically include a regenerative braking system to recapture braking energy to the battery that would otherwise be lost. Previous analysis of the costs of these systems suggest that there are incremental costs associated with regenerative braking systems compared with standard braking, but that these costs are relatively modest. We assume that the cost-per-weight of the regenerative braking systems are 5% higher than the cost-per-weight of standard braking systems (see Delucchi et al., 2001 for details).

Lifecycle Cost Assumptions

With regard to the analysis of vehicle lifecycle costs, the various methods used in the model for these intricate calculations are described in Delucchi et al. (2001). In general, vehicle lifecycle costs are estimated as function of the following factors:

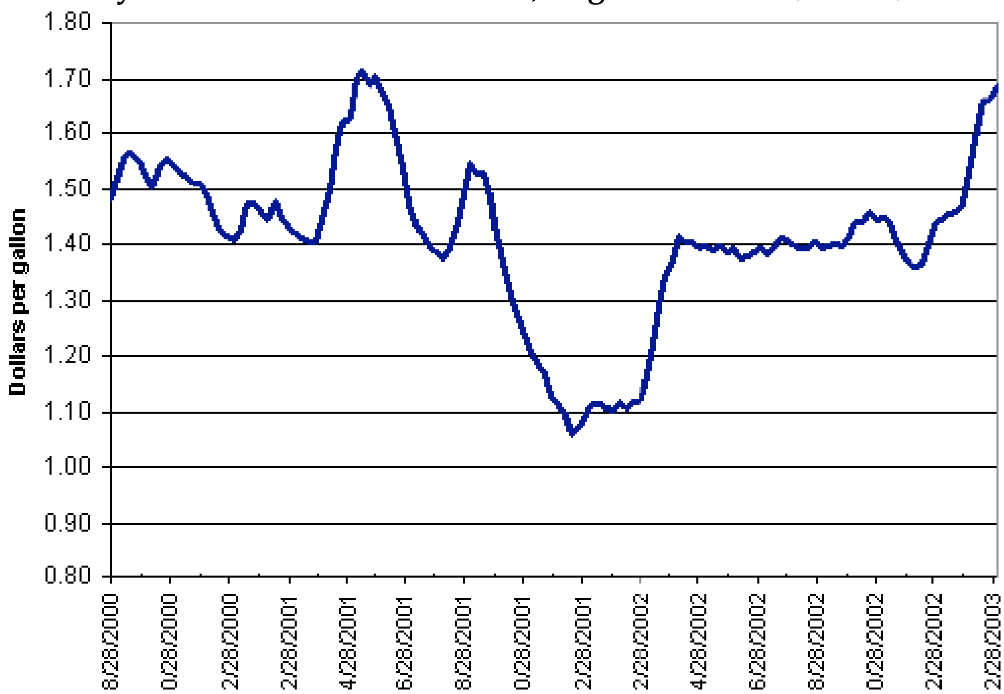
- Vehicle capital cost (amortized over the life of the vehicle);
- Battery and tray and auxiliaries (initial and replacements, amortized over the life of vehicle and assuming NiMH "Gen 4" battery technology);
- Fuel costs;
- Insurance (calculated as a function of VMT and vehicle value);
- Maintenance and repair, excluding oil, inspection, cleaning, towing;
- Engine oil (for all vehicle systems);
- Replacement tires (calculated as a function of VMT, and vehicle weight);
- Parking, tolls, fines, and accessories (same for all vehicles);
- Registration fee (calculated as a function of vehicle weight);
- Vehicle safety and emissions inspection fee; and

[5] The question being not whether or not this is technically feasible, but rather the extent to which such electric motor "bump-start" strategies can be smoothly integrated into HEV drivelines with good driveability while the vehicle is in motion.

• Federal, state, and local fuel excise taxes.

Our analysis assumes a base gasoline national average retail price of $1.46 per gallon (year 2000 $s), and this is composed of a wholesale price of $1.00 per gallon, a retail station markup of $0.08 per gallon, and total federal, state, and local taxes of $0.38 per gallon. This gasoline price is close to national average gasoline prices in recent history, although certain regions (particularly the West Coast and Midwest) occasionally experience price spikes that approach or even exceed $2.00 per gallon. Figure 3 shows regular grade gasoline prices in the U.S. over the past few years, and the very recent (early 2003) increase in average prices.

Figure 3: Weekly U.S. Retail Gasoline Prices, Regular Grade (8/2000-2/2003)



Source: EIA, 2003

With regard to interest rate assumptions for the lifecycle cost and gasoline breakeven price analyses, these are not based on a single interest rate, but rather involve several different calculations and the following interest rates: a 7% real rate on new car purchases for those that are assumed to be financed, a 6% real rate for the opportunity cost of money for auto manufacturers, and a 3.9% interest rate for the consumer "opportunity cost" of purchasing a vehicle relative to alternative uses of the same money.

We estimate the maintenance and repair (m&r) costs for HEVs in a similar fashion as we have in the past estimated them for BEVs, by using our estimates for ICEV maintenance costs as a baseline and then by distinguishing between vehicle components that are common to the two vehicle types and those that are unique to the HEVs, and then estimating the m&r costs associated with the unique HEV componentry. More specifically, we arrive at estimated m&r cost schedules for the

HEVs by: 1) estimating fleet-average lifetime maintenance and repair costs for ICEVs, in $ per vehicle per year, using Bureau of the Census data; 2) distinguishing m&r costs that are the same for HEVs and ICEVs, costs that are unique to ICEVs or HEVs, and costs that are "common to but not exactly the same" for ICEVs and HEVs; 3) estimating the HEV costs relative to the ICEV costs for those costs that are unique to HEVs and common to but not the same for HEVs and ICEVs; 4) converting the fleet-average lifetime estimates into year-by-year maintenance cost schedules, for different vehicle types; 5) updating costs to target year using the Consumer Price Index; and 6) finally, estimating HEV m&r "common" costs relative to ICEV m&r "common" costs based on components sizes and aggregate all m&r cost estimates for each vehicle type.

With regard to costs of battery replacements for HEVs, sensitivity analysis on this important lifecycle cost parameter is presented below and shown in Table 10, for one example, in order to show the general sensitivity of results to battery lifetime and replacement cost assumptions. In our base case, we assume a 7.5-year battery life, or that two battery packs can meet the full 15-year vehicle life, but we also examine 5, 10, and 15-year battery lives in sensitivity analysis. In the base case, we assume that the replacement cost of the battery pack is 85% of the cost of a new battery pack (at the retail level) due to somewhat lower overhead on replacement parts relative to similar parts on a new vehicle. In the sensitivity analysis below, we also show results for replacement costs of 50% of the new battery (assuming reconditioned packs) and 100% of the new battery (again, see Table 10 below).

VII. Analysis Results and Conclusions

Principal findings from this analysis are that estimated HEV retail prices range from approximately $2,500 to $6,700 more than the estimated retail prices of the baseline ICEVs. In general, the HEV price effects are highest for the MF cases, second highest for the AF1 cases, third highest for the AF2 cases, fourth highest for the MM cases, and lowest for the AM cases.[6] Interestingly, this suggests that the advanced cases, despite the additional costs associated with this package of benefits, tend to look attractive relative to the moderate cases for similar levels of hybridization. In other words, the benefits of mass reduction along with better engine and transmission technology appear to make incorporation of the advanced package of benefits an attractive overall cost-minimizing strategy for these HEVs. The additional costs of these AM vehicles are relatively modest, and the fuel economy gains are therefore achieved in a relatively cost-effective fashion from a vehicle lifecycle cost perspective.

Table 8 and Figures 4 through 6, below, present the key vehicle retail price, "HEV retail price increase," and vehicle lifecycle cost and gasoline breakeven-price results for this analysis. In addition to the five main vehicle types analyzed, also shown in Table 8 are illustrative results for approximate designs of the "Prius" and "Civic Hybrid" vehicles. We include these additional cases out of interest and for potential "benchmarking" purposes.

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[6]As shown in Table 3:
MM = moderate package of improvements, mild hybridization
MF = moderate package of improvements, full hybridization
AM = advanced package of improvements, mild hybridization
AF1 = advanced package of improvements, full hybridization case 1
AF2 = advanced package of improvements, full hybridization case 2

In general, the HEV designs with the lowest HEV price effects are the AM cases, followed respectively by the MM, AF2, AF1 and finally the MF cases. This demonstrates that greater degrees of hybridization (i.e. a higher proportion of power from the electric part of the driveline) imply higher vehicle retail prices, primarily due to the cost of the battery, and again that the "advanced" package of vehicle mass and drag and efficiency improvement cases are relatively attractive in comparison with the "moderate" package of improvement cases.

Table 8: Full Retail Price and Gasoline Breakeven Cost Summary – HEVs vs. Baseline ICEVs High Volume Production (Year 2000 $s)

	Gasoline ICEV	Moderate Mild HEV	Moderate Full HEV	Advanced Mild HEV	Advanced Full HEV 1	Advanced Full HEV 2
Cavalier MSRP	$15,100 $14,295	$17,797 $16,902	$19,351 $18,402	$17,643 $16,764	$18,826 $17,908	$18,485 $17,577
HEV Price Effect ($)		$2,697	$4,251	$2,543	$3,726	$3,385
Gas Breakeven ($/gal)		$2.03	$2.46	$1.80	$2.20	$2.04
Taurus MSRP	$20,461 $19,344	$23,217 $22,026	$24,843 $23,602	$23,039 $21,876	$24,701 $23,467	$24,256 $23,049
HEV Price Effect ($)		$2,756	$4,382	$2,578	$4,240	$3,795
Gas Breakeven ($/gal)		$1.82	$2.30	$1.68	$2.04	$1.84
Silverado MSRP	$25,714 $24,350	$29,492 $28,027	$32,408 $30,842	$29,104 $27,692	$31,001 $29,527	$30,537 $29,079
HEV Price Effect ($)		$3,778	$6,694	$3,390	$5,287	$4,823
Gas Breakeven ($/gal)		$1.93	$2.65	$1.60	$2.05	$1.86
Caravan MSRP	$24,541 $23,264	$27,703 $26,335	$29,368 $27,950	$27,307 $25,983	$28,929 $27,554	$28,471 $27,110
HEV Price Effect ($)		$3,162	$4,827	$2,766	$4,388	$3,930
Gas Breakeven ($/gal)		$1.79	$2.21	$1.49	$1.89	$1.72
Explorer MSRP	$28,225 $26,778	$31,686 $30,141	$33,944 $32,326	$31,759 $30,245	$33,434 $31,868	$32,951 $31,400
HEV Price Effect ($)		$3,461	$5,719	$3,534	$5,209	$4,726
Gas Breakeven ($/gal)		$1.94	$2.52	$1.73	$2.14	$1.96
'Prius' Hybrid Full Retail Price			$19,746			
HEV Price Effect ($)			$4,646			
Gas Breakeven ($/gal)			2.57			
'Civic' Hybrid Full Retail Price		$17,460				
HEV Price Effect **($)**		$2,360				
Gas Breakeven ($/gal)		1.74				

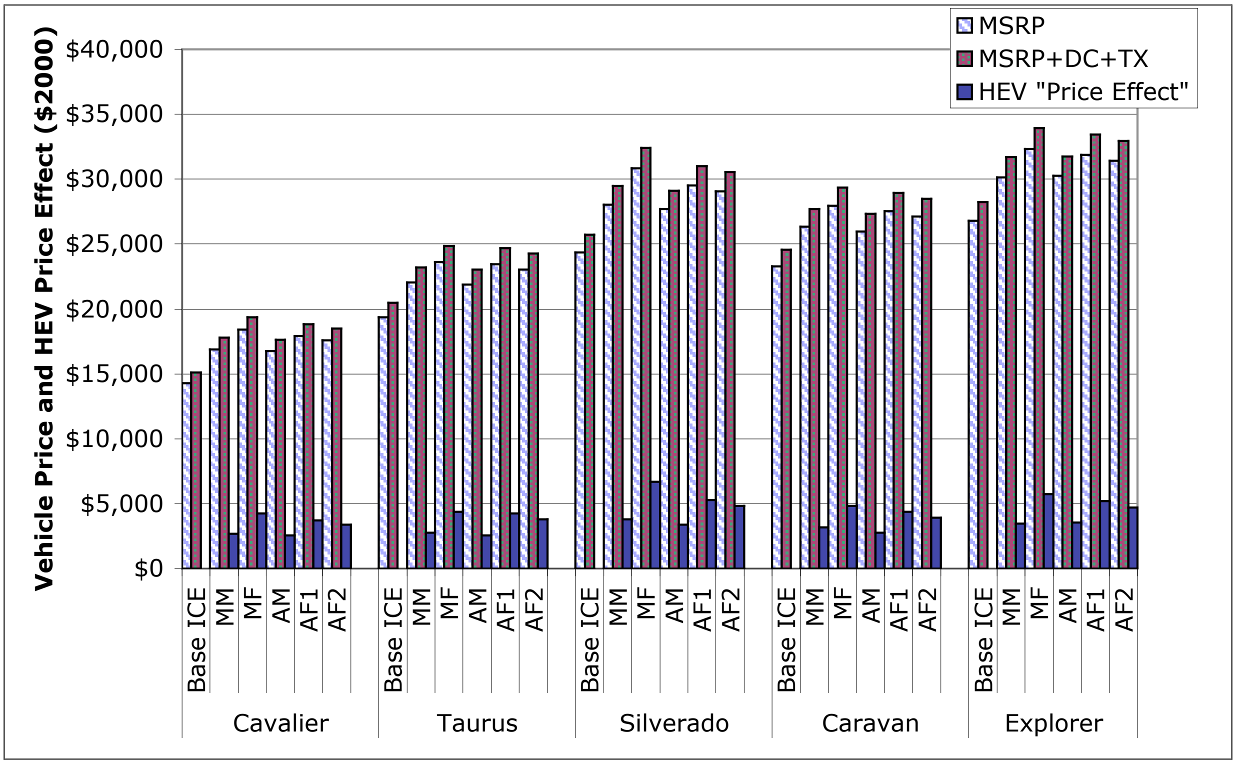
Notes:
The first vehicle price listed is the full retail price to consumer including destination charge and 3% sales

tax additions to the MSRP value, shown just below.

"HEV Price Effect" Values are based on the full retail price estimates; price differentials based on the MSRPs are approximately 2-3% lower (typically about $100-200 lower).

Gasoline breakeven cost values are based on the "real world" fuel economy values from Friedman and An (2003), shown in Table 4. The gasoline breakeven price values represent the price of gasoline, including all excise taxes, at which the lifecycle cost-per-mile of an HEV model equals the lifecycle cost-per-mile of the comparable baseline gasoline vehicle.

Figure 4: Vehicle Full Retail, MSRP, and HEV "Price Effect" Estimates



One important aspect of advanced vehicle manufacturing and retail cost analyses is the manner and degree to which the estimated vehicle manufacturing costs then get "marked up" to the dealer invoice price, the MSRP, and the full vehicle retail price. The manner in which this is done in the vehicle cost model used for this analysis is somewhat complex, as the markups are not typically simple functions of any one variable but rather include several subtleties. We refer readers to Delucchi, et al. (2001) for detailed explanations of these markups, but we include Table 9, below, to illustrate these various markups for one sample HEV/ICEV comparison case, including a more detailed breakdown of the corporate, division, and dealer-level markups than we include in the detailed results tables in Appendix A.

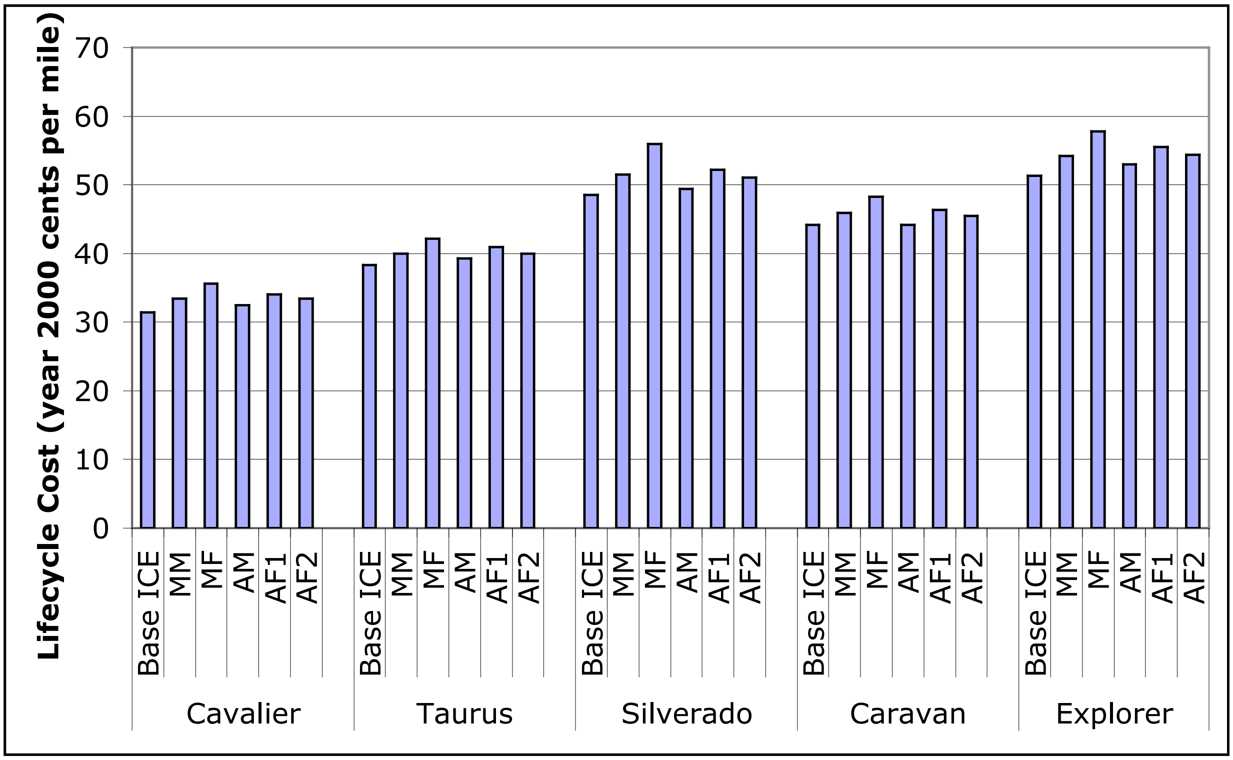
Table 9: Example Manufacturing Cost and Retail Price Breakdown-Cavalier MM Case

Cost Category	ICEV	HEV
Total Manufacturing Cost	***$5,741***	***$7,587***
Division costs (engineering, testing, advertising)	$3,761	$4,124
Corporate costs (executives, capital, research and development)	$2,222	$2,300
Corporate cost of money	$172	$206
Corporate true profit (taken as fraction of factory invoice)	$368	$440
Factory Invoice (price to dealer)	***$12,265***	***$14,656***
Dealer costs	$2,031	$2,246
Manufacturer's Suggested Retail Price (MSRP)	***$14,295***	***$16,902***
Shipping cost (destination charge)	$365	$377
Retail Cost to Consumer (includes shipping cost and 3% tax)	***$15,100***	***$17,797***

Notes:
Division costs include all costs associated with these corporate divisions, except costs in the manufacturing plants (which already have been counted in the manufacturing-cost analysis): full salary-plus-benefits of engineers, vehicle testers, managers, administrators, division executives, and everyone else who works in the division but not in a manufacturing plant; the operating and maintenance costs of division facilities (except manufacturing plants); and advertising for division products.
Corporate costs include the full salary-plus-benefits of corporate executives, research and development activities, the cost of money, capital equipment (including facilities), corporate advertising, and corporate profit (as distinct from the cost of money).
The corporate cost of money is the cost to the automaker of money invested in the vehicle before it is sold, and is proportional to the amount of money invested, the length of time between when the investments are made and when the vehicle is sold, and the interest rate (we assume a 6% real rate).
Corporate true profit is calculated as a function of dealer invoice price, and is assumed to be 3% of dealer invoice for this analysis.
Dealer costs included the dealer costs associated with selling the vehicle, as well as the dealer cost of warranty maintenance and repair.
Shipping costs are the costs of final delivery of the vehicle from the factory to the dealer, and are estimated as a function of vehicle weight (we assume the same shipping distances for all vehicles).

With regard to the vehicle lifecycle cost estimates, Figure 4 shows these results for the HEVs and the comparison baseline vehicles. In general, the variations in vehicle lifecycle costs, among the HEVs and relative to the base ICEVs, are lower than for vehicle retail prices. This is because the more expensive HEVs also tend to have higher fuel economy values, and this helps to "even out" the lifecycle costs. In general, HEVs have slightly higher drivetrain, insurance, and m&r costs than the comparable conventional vehicles, expressed in amortized cents per mile, but significantly lower fuel costs per mile, and relatively high battery costs per mile. HEV battery plus fuel costs in comparison to ICEV fuel costs are main source of differences among the lifecycle cost categories, but the amortized vehicle cost is also a significant factor.

Figure 5: Vehicle Lifecycle Cost Estimates

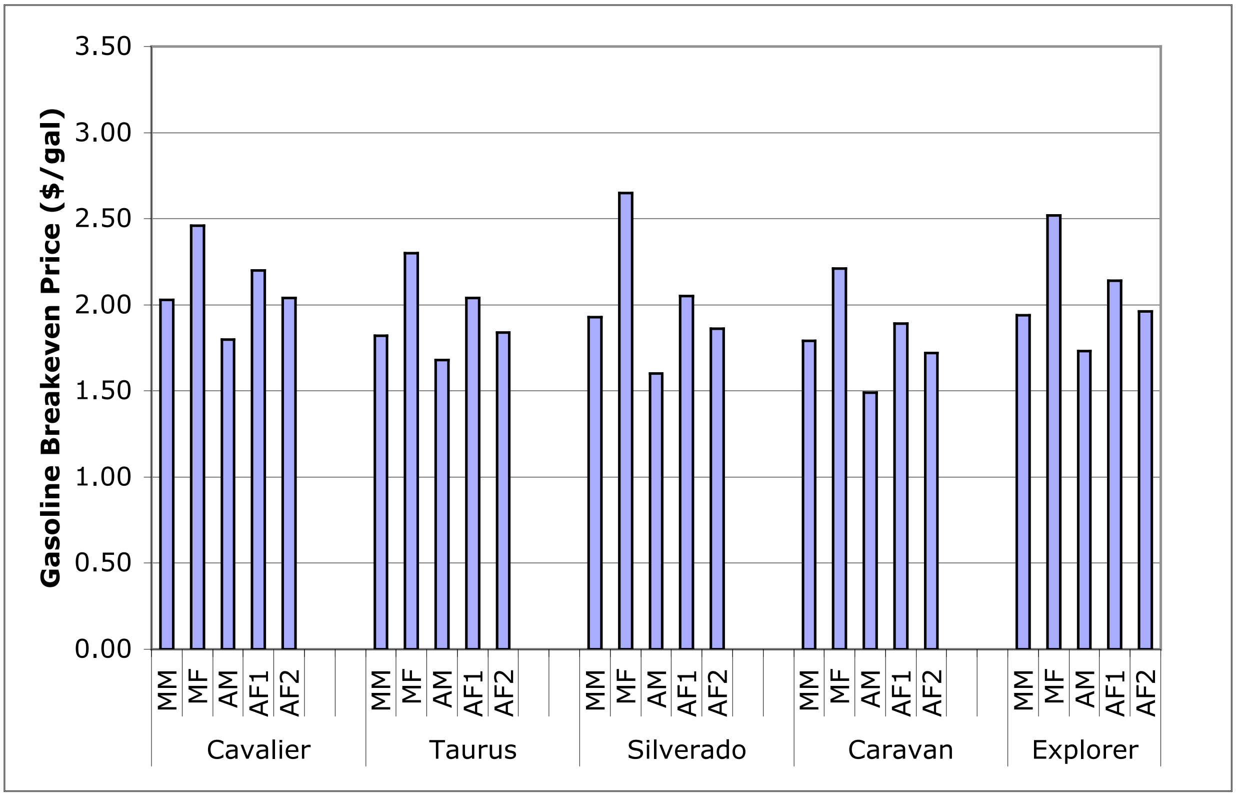


Note: Vehicle lifecycle cost assumes gasoline retail price of $1.46 per gallon including all taxes (Year 2000 $s).

As with the vehicle price analysis, the AM cases again look attractive with lifecycle costs that are very close to those of the baseline vehicles (and almost identical in the case of the Caravan). The other cases all have somewhat higher lifecycle costs than the base ICEVs, with the MM and AF2 cases typically a few cents per mile higher than the comparable ICEVs and the MF and AF1 cases a few cents per mile higher than the MM and AF2 cases.

Figure 6 presents the results of the gasoline breakeven price analysis, which assumes $1.46 per gallon gasoline for a U.S. national average (in year 2000 $s). As shown in the figure, lifecycle gasoline breakeven prices range from $1.49 per gallon to $2.65 per gallon, illustrating that none of HEV designs that we analyze would actually save consumers money over the vehicle lifetime but that some would come very close. Using different assumptions about interest rates, and the price of gasoline over time, one could clearly arrive at different conclusions from these same results, with at least a few of the HEV designs potentially having lower net lifetime operating costs than the comparable baseline ICEVs.

Figure 6: Gasoline Breakeven Price Estimates



Battery Cycle Life and Replacement Cost Sensitivity Analysis

As noted above, for purposes of this analysis we do not model battery performance in detail, but rather assume in the base case that the NiMH batteries used in the various HEV designs all last for about 7 and a half years, or half the assumed vehicle lifetime of 15 years. This assumption means that exactly 2 battery packs are needed during the lifetime of each vehicle. We also assume that the replacement battery pack is somewhat less expensive than the initial battery, with a replacement cost of 85% of the initial battery pack price, due to what we believe to be lower manufacturer overheads for these replacement battery packs (Delucchi, et al., 2001).

In order to assess the general impact of variations in these battery life and replacement cost assumptions, we focus on one example and vary these assumptions to gain a sense of the sensitivity in HEV lifecycle costs estimates to the assumed values. First, we examine the impact on lifecycle cost on the battery lifetime assumption by analyzing sensitivity cases in which the battery: 1) lasts for 5 years rather than 7.5 years, thereby requiring two battery replacements rather than one; 2) lasts for 10 years, thereby requiring a battery replacement later in the vehicle life and with some salvage value of the battery remaining at the end of the 15-year vehicle life; and 3) lasts for the full 15-year life of the vehicle. Second, we vary the battery replacement cost assumption by considering cases in which the replacement battery costs 50% as much as the initial battery (in the even that battery costs drop from the time of vehicle purchase to the time of the battery replacement, or that relatively inexpensive reconditioned battery packs with adequate performance can be used), and in which the replacement cost is 100% of the initial battery cost. Table 10, below, shows the impact on HEV lifecycle cost of these various assumptions, in comparison with the "base case" battery life assumption, for the sample "Cavalier AM" case.

Table 10: Sensitivity Analysis for Battery Life and Replacement Cost on HEV Lifecycle Cost – Cavalier AM Case Example

Assumed Battery Life (years and % of 15-year vehicle life)	ICEV (cents per mile)	Battery Cycle Life (cycles)	HEV (cents per mile)	HEV Battery (cents per mile)
5 Years (33%)	31.16	965	32.87	1.47
7.5 Years (base case) (50%)	31.16	1,331	32.50	1.11
10 Years (67%)	31.16	1,642	32.38	0.99
15 Years (100%)	31.16	2,219	32.13	0.74
Assumed Battery Replacement Cost (with 7.5 year battery life) (% of initial battery cost)				
50%	31.16	1,331	32.35	0.95
85% (base case)	31.16	1,331	32.50	1.11
100%	31.16	1,331	32.56	1.17

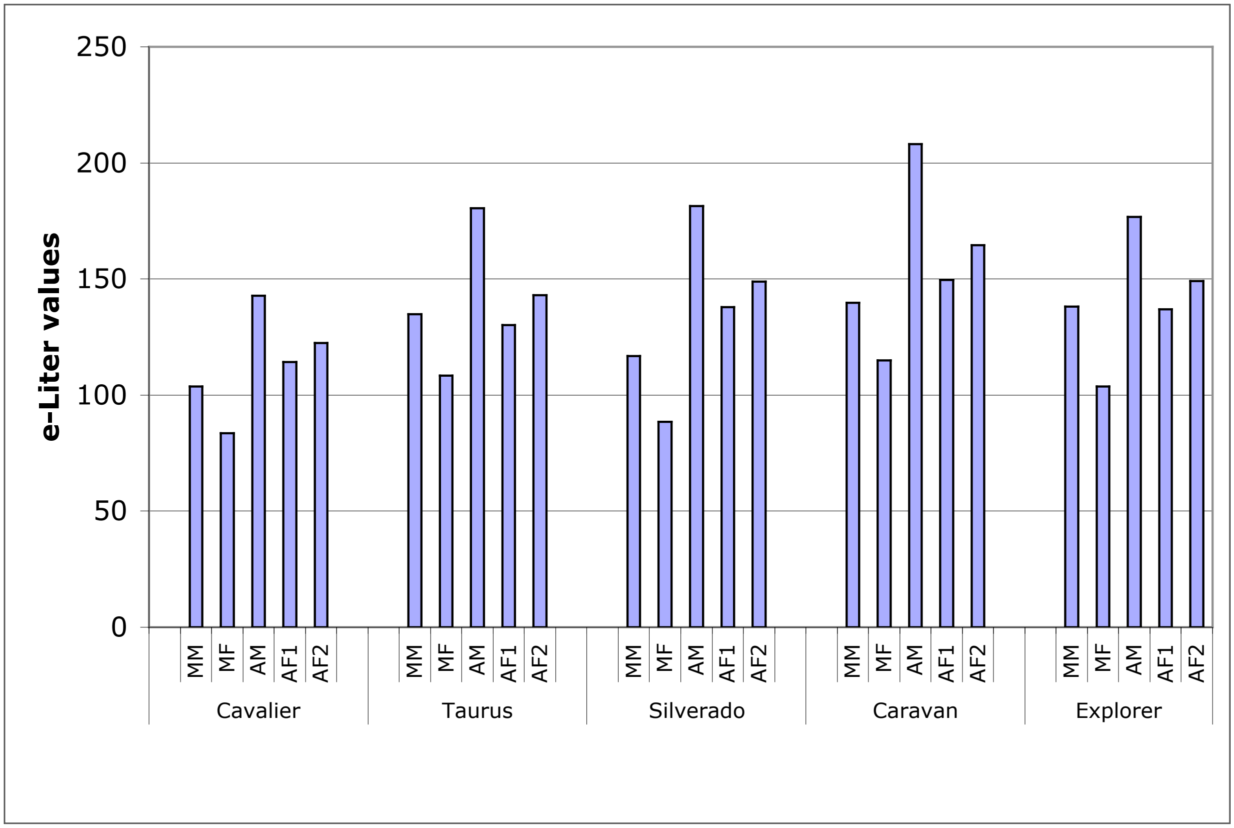
Note: HEV Battery includes both initial and replacement battery costs.

These sensitivity analysis results show that the HEV lifecycle costs are sensitive to variations in these assumptions, but that the changes that we consider above have relatively modest impacts on the overall HEV lifecycle costs. None of the variations that we consider have an impact of more than 0.40 cents per mile in the overall vehicle lifecycle costs for this "Cavalier AM" example. This is in part due to the fact that the impacts of these variations in battery life and replacement cost are "damped" by the fact that future costs, such as battery replacement costs, are discounted in the lifecycle cost calculations.

Comparison with Other Studies

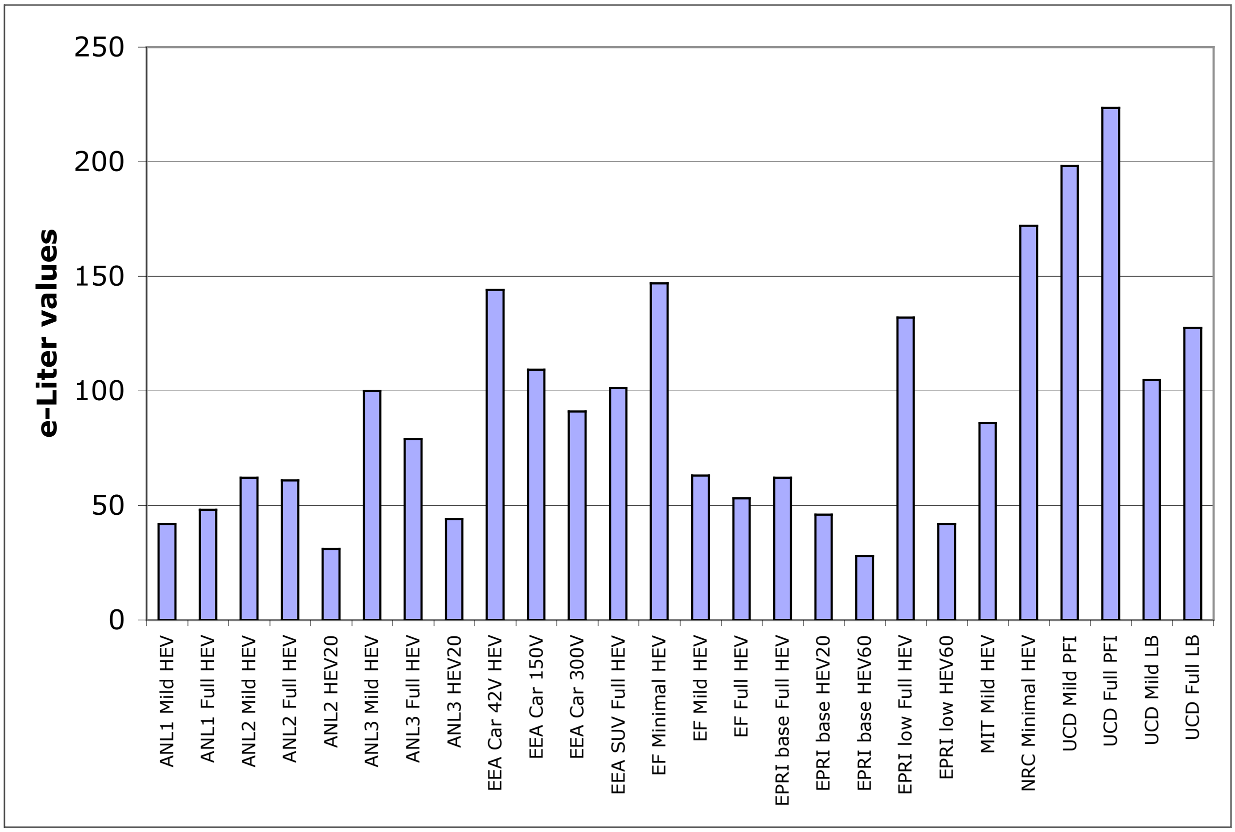
One interesting measure for comparing the results of vehicle "cost of fuel economy improvement" studies is the "e-Liter" measure recently suggested by Santini et al., 2002a that corrects for the problem of misleading results from the use of some other measures. This measure expresses the benefit-cost implications of each additional step of improvement to a vehicle's fuel economy in terms of "liters of gasoline saved per 10,000 km of travel per $1,000 of additional vehicle cost." In addition to the basic incremental cost results shown in Table 8 and the appendix tables, we present our results in terms of this e-Liter measure in the figure below. As shown in Figures 7 and 8, our results are somewhat more encouraging than most studies with regard to the potential costs of vehicle fuel economy improvement. We attribute this result to the combination of the forward-looking and high-volume production nature of this study (looking out to the 2010-2012 timeframe), the "synergistic" effects that we seem to be finding with regard to the benefits of moving to advanced packages of vehicle mass and drag reduction (in terms of reduced size and cost of the drivetrain), and other differences in the assumptions made in the various studies.

Figure 7: "e-Liter" Values – Fuel Saved Over 10,000 km per Incremental Vehicle Price in This Study



Note: "e-Liter" is liters of fuel saved over 10,000 km of driving per $1000 of incremental vehicle price.

Figure 8: "e-Liter" Values – Fuel Saved Over 10,000 km per Incremental Vehicle Price in Other Studies



Notes: "e-Liter" is liters of fuel saved over 10,000 km of driving per $1000 of incremental vehicle price. These studies include various vehicle types and designs, and differing assumptions about vehicle performance. Please see individual studies for details (cited in the references section).

Conclusions

In conclusion, we have arrived at several important insights from this combination of the Friedman and An (2003) HEV performance analysis with our HEV retail price and lifecycle cost modeling framework and analysis. These primary results and key insights, along with those noted in the following paragraph regarding our planned future work in this area, are as follows:

- the "HEV Price Effects" of the various options range from $2,543 (Cavalier AM case) to $6,694 (Silverado MF case) and are as follows, based on the estimated full retail price of the vehicles to consumers:

Vehicle Type	HEV Price Effect (Year 2000 $s)				
	MM Case	MF Case	AM Case	AF1 Case	AF2 Case
Cavalier	$2,697	$4,251	$2,543	$3,726	$3,385
Taurus	$2,756	$4,382	$2,578	$4,240	$3,795
Silverado	$3,778	$6,694	$3,390	$5,287	$4,823
Caravan	$3,162	$4,827	$2,766	$4,388	$3,930
Explorer	$3,461	$5,719	$3,534	$5,209	$4,726

- the vehicle lifecycle cost disparities between the HEVs and baseline vehicles are somewhat lower in relative terms than the retail price differences, with lifecycle costs of some HEVs (and particularly the AM designs) in some cases being very similar to those of the baseline vehicles even though their retail prices are a few thousand dollars higher (note that the lifecycle cost analysis assumes a gasoline price for all vehicles of $1.46 per gallon including all taxes);

- the gasoline breakeven prices that we calculate for the various HEVs in comparison with the baseline ICEVs range from $1.49 per gallon to $2.65 per gallon, and the low end of this range is very close to the $1.46 per gallon assumed price in the study, again suggesting that at least a few of the HEV designs are very close to being economically competitive on a lifecycle cost basis;

- given the various assumptions and estimates used in this analysis, it appears that combining the "advanced package of vehicle improvements" with "mild vehicle hybridization" (AM case) provides what generally is the least-cost solution of the HEV options and that has lifecycle costs very close to those of the baseline vehicles; and

- these AM cases may be close to a set of "optimized" cases in terms of both cost and performance, for the various vehicle types but if fuel economy gains are valued more highly (such as through carbon taxes or oil import externality taxes, or through a "social cost analysis") then the more fuel efficient options, and in particular the AF2 cases, might look attractive as well.

With regard to these conclusions and this analysis in general, we would like to emphasize that we have accomplished this analysis by combining a thorough HEV design and performance analysis conducted by colleagues with a detailed HEV cost analysis using a vehicle manufacturing cost and lifecycle cost spreadsheet model. Our analysis is internally consistent in the sense that we attempt to analyze the costs of the same vehicles whose performance has been characterized by Friedman and An (2003), but we consider this to also be an important step toward developing a fully integrated HEV analysis within the spreadsheet model (i.e. where the vehicle is "designed" in the spreadsheet model and through its detailed energy use analysis, rather than Advisor's).

We also note that we have only recently obtained the data that have allowed us to characterize the costs of the SUV and pickup truck vehicle styles, and that we will be continuing to refine our analysis of the costs of different body styles and structures in the near future. This will be particularly useful in more carefully analyzing and understanding the costs of vehicle mass and drag reduction in high-volume production (e.g. through high-strength steel, lightweight alloys, composites, etc.) as well as the impacts of more revolutionary concepts such as "drive-by-wire" systems. For purposes of this analysis we have assumed that relatively optimistic vehicle mass reductions are possible by the 2010 timeframe for some of the analysis cases, but we hope to further bolster these estimates in the future with more detailed data and analysis in collaboration with our industry-based colleagues. On the other hand, however, we note that our NiMH battery cost estimates are a few years out of date, and based on other estimates that we have seen, they may be somewhat conservative. Finally, we note that we have focused in this study on HEVs that generally employ a "one motor, NiMH battery" design, but in principle HEVs can employ two to four drive motors as well as using other battery types as well as ultracapacitors for electrical power. We refer to one study that compares HEV designs that use NiMH batteries and those that use ultracapacitors (Burke et al., 2002), and we hope to include both lithium-based batteries and ultracapacitors in our future work.

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Appendix A: Detailed Results Tables

(Note: HEV AF2 case results follow the results for the MM, MF, AM, and AF1 cases)

Table A-1: Retail Price and Gasoline Breakeven Cost Summary – HEVs vs. Baseline ICEVs High Volume Production (Year 2000 $s)

	Gasoline ICEV	Moderate Mild HEV	Moderate Full HEV	Advanced Mild HEV	Advanced Full HEV 1	Advanced Full HEV 2
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HEV Price Effect **($)**		$2,360				
Gas Breakeven ($/gal)		1.74				

Notes: The first vehicle price listed is the full retail price to consumer including destination charge and 3% sales tax additions to the MSRP value, shown just below.

"HEV Price Effect" Values are based on the full retail price values, price differentials based on the MSRPs are approximately 2-3% lower (typically about $100-200 lower).

Gasoline breakeven cost values are based on "EIA cycle" fuel economy estimates. These values represent the retail price of gasoline for the HEVs and baseline vehicles that would produce the same vehicle lifecycle cost values for both vehicles.

Cavalier / Compact

Table A-2: Summary of Vehicle Characteristics – Cavalier / Compact
(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate/ Mild	Moderate/ Full	Advanced/ Mild	Advanced/ Full 1
Type of traction battery	n.a.	NiMH Gen4	NiMH Gen4	NiMH Gen4	NiMH Gen4
Type of electric motor	n.a.	UQM BPM	UQM BPM	UQM BPM	UQM BPM
Type of combustion engine	2.2 L Inline-4	1.5 L VTEC Inline-4	1.1 L VTEC Inline-3	1.1 L GDI Inline-3	0.8 L GDI Inline-3
Total gross power of drive system (kW)	85.8	86.7	90.0	73.3	75.0
Acceleration, 0 to 60 mph, 0% grade w/payload (sec)		10.0	9.6	9.5	9.3
Gasoline engine peak power (kW)	85.8	73.7	54.0	62.3	45.0
Electric motor peak power (kW)	n.a.	13.0	36.0	11.0	30.0
Battery module power density (W/kg)	n.a.	727	728	790	812
Battery cycle life to 80% DoD	n.a.	1,331	1,331	1,331	1,331
Battery life (years)	n.a.	7.6	7.6	7.6	7.6
Battery system specific energy (Wh/kg)	n.a.	36	36	34	33
Battery energy (kWh)	n.a.	0.89	2.4	0.65	1.7
Battery weight (kg)	n.a.	24	66	19	50
Volume of battery in HEV / fuel tank in ICEV (L)	52	5	13	4	10
Vehicle life (km)	273,530	273,530	273,530	273,530	273,530
Weight of the complete vehicle (kg)	1,420	1,393	1,459	1,266	1,294
Coefficient of drag	0.360	0.324	0.324	0.324	0.324
Fuel economy - CAFE Cycle (gasoline-equiv. mpg)	30.8	48.6	57.6	58.7	69.6
Fuel economy - EIA Cycle (gasoline-equiv. mpg)	25.3	39.9	47.2	48.1	57.1
Fuel economy - EIA Cycle (gasoline-equiv. L/100 km)	9.3	5.9	5.0	4.9	4.1

Table A-3: Summary of Vehicle Costs – Cavalier / Compact

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Fuel retail price, excluding taxes ($/GEG)	1.07	1.07	1.07	1.07	1.07
Full retail price of vehicle, incl. taxes and shipping ($)	**15,100**	**17,797**	**19,351**	**17,643**	**18,826**
Manufacturer's suggested retail price (MSRP) ($)	14,295	16,902	18,402	16,764	17,908
Dealer invoice price ($)	12,265	14,656	16,032	14,529	15,579
Manufacturing cost ($)	5,741	7,587	8,649	7,489	8,299
Battery contribution to retail price ($)	n.a.	1,183	3,121	950	2,446
Battery contribution to retail cost ($/kWh)	n.a.	1,361	1,299	1,496	1,482
IC engine and engine assembly contribution to retail price ($)	1,362	1,629	1,442	1,846	1,657
Motor/controller/inverter contribution to retail price ($)	n.a.	1,781	2,226	1,716	2,142
Transmission contribution to retail price ($)	539	475	447	446	421
Levelized maintenance cost ($/yr)	605	684	694	670	679
Total lifecycle cost (cents/km)	31.43	33.40	35.57	32.50	34.07
Present value of lifetime cost vs. gasoline ($)*	42,217	3,025	5,603	1,806	3,943
Breakeven gasoline price ($/gal)	n.a.	2.03	2.46	1.80	2.20

*For gasoline, the present value is shown; for the HEVs, the difference in the present value vs. gasoline is shown.

Table A-4: Summary of Lifecycle Costs – Cavalier / Compact
(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 cents/mile)

Cost item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Battery and tray and auxiliaries (NiMH Gen4)	n.a.	1.38	3.65	1.11	2.85
Vehicle, excluding battery	11.58	12.67	12.41	12.71	12.50
Motor fuel, excluding excise taxes and electricity	4.43	2.68	2.26	2.22	1.87
Fuel-storage system	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle
Insurance (calculated as a fn of VMT and vehicle cost)	5.52	6.20	6.58	6.16	6.45
Maintenance and repair, excluding oil and inspection	5.37	6.07	6.16	5.94	6.02
Engine oil	0.14	0.09	0.09	0.09	0.09
Replacement tires (calculated as a fn of VMT and wgt)	0.41	0.40	0.41	0.39	0.40
Parking, tolls, and fines (same for all vehicles)	1.06	1.06	1.06	1.06	1.06
Registration fee (calculated as a fn of vehicle wgt)	0.41	0.40	0.42	0.37	0.37
Vehicle safety and emissions inspection fee	0.56	0.56	0.56	0.56	0.56
Federal, state, and local fuel (energy) excise taxes	1.64	1.56	1.64	1.56	1.56
Accessories (assumed to be the same for all vehicles)	0.32	0.32	0.32	0.32	0.32
Dollar value of external costs (air pollution, noise, climate change, oil use)	not counted	not counted	not counted	not counted	not counted
Total lifecycle cost (cents/mile)	**31.43**	**33.40**	**35.57**	**32.50**	**34.07**
The price of gasoline, including taxes, that equates the lifecycle consumer cost of the gasoline vehicle with the lifecycle consumer cost of the electric vehicle ($/gal)	n.a.	***2.03***	***2.46***	***1.80***	***2.20***

Taurus / Mid-Sized

Table A-5: Summary of Vehicle Characteristics – Taurus / Mid-Sized

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Type of traction battery	n.a.	NiMH Gen4	NiMH Gen4	NiMH Gen4	NiMH Gen4
Type of electric motor	n.a.	UQM BPM	UQM BPM	UQM BPM	UQM BPM
Type of combustion engine	3.0 L V-6	1.8 L VTEC Inline-4	1.3 L VTEC Inline-4	1.3 L GDI Inline-4	1.0 L GDI Inline-3
Total gross power of drive system (kW)	115.6	106.7	110.0	90.7	92.5
Acceleration, 0-60 mph, 0% grade w/payload (sec)		8.9	8.8	8.8	8.8
Gasoline engine peak power (kW)	115.6	90.7	66.0	73.7	55.5
Electric motor peak power (kW)	n.a.	16.0	44.0	13.0	37.0
Battery module power density (W/kg)	n.a.	704	729	813	813
Battery cycle life to 80% DoD	n.a.	1,331	1,331	1,331	1,331
Battery life (years)	n.a.	7.6	7.7	7.6	7.6
Battery system specific energy (Wh/kg)	n.a.	37	36	33	33
Battery energy (kWh)	n.a.	1.1	2.9	0.7	2.0
Battery weight (kg)	n.a.	30	81	22	62
Volume of battery in HEV / fuel tank in ICEV (L)	86	6	16	4	12
Vehicle life (km)	273,530	273,530	273,530	273,530	273,530
Weight of the complete vehicle (kg)	1,648	1,471	1,572	1,313	1,356
Coefficient of drag	0.320	0.288	0.288	0.288	0.288
Fuel economy - CAFE Cycle (gasoline-equiv. mpg)	26.2	44.7	55.6	54.4	68.1
Fuel economy - EIA Cycle (gasoline-equiv. mpg)	21.5	36.7	45.6	36.7	55.8
Fuel economy - EIA Cycle (gasoline-equiv. L/100 km)	11.0	6.4	5.2	6.4	4.2

Table A-6: Summary of Vehicle Costs – Taurus / Mid-Sized

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Fuel retail price, excluding taxes ($/GEG)	1.07	1.07	1.07	1.07	1.07
Full retail price of vehicle, incl. taxes and shipping ($)	**20,461**	**23,217**	**24,843**	**23,039**	**24,701**
Manufacturer's suggested retail price (MSRP) ($)	19,344	22,026	23,602	21,876	23,467
Dealer invoice price ($)	16,162	18,587	20,012	18,451	19,900
Manufacturing cost ($)	8,584	10,529	11,672	10,420	11,583
Battery contribution to retail price ($)	n.a.	1,398	3,624	1,032	2,832
Battery contribution to retail cost ($/kWh)	n.a.	1,234	1,237	1,447	1,394
IC engine and engine assembly contribution to retail price ($)	3,271	3,330	2,894	3,236	2,895
Motor/controller/inverter contribution to retail price ($)	n.a.	1,763	2,249	1,678	2,139
Transmission contribution to retail price ($)	920	810	770	749	721
Levelized maintenance cost ($/yr)	617	689	699	671	684
Total lifecycle cost (cents/km)	38.30	39.97	42.14	39.29	40.93
Present value of lifetime cost vs. gasoline ($)*	51,876	2,266	5,236	1,375	3,594
Breakeven gasoline price ($/gal)	n.a.	1.82	2.30	1.68	2.04

*For gasoline, the present value is shown; for the HEVs, the difference in the present value vs. gasoline is shown.

Table A-7: Summary of Lifecycle Costs – Taurus / Mid-Sized

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 cents/mile)

Cost item	**ICEV**	**Moderate Mild**	**Moderate Full**	**Advanced Mild**	**Advanced Full 1**
Battery and tray and auxiliaries (NiMH Gen4)	n.a.	1.64	4.26	1.21	3.34
Vehicle, excluding battery	15.95	16.85	16.47	17.00	16.98
Motor fuel, excluding excise taxes and electricity	4.98	2.91	2.34	2.91	1.92
Fuel-storage system	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle
Insurance (calculated as a fn of VMT and vehicle cost)	6.89	7.57	7.97	7.53	7.94
Maintenance and repair, excluding oil and inspection	5.47	6.11	6.20	5.96	6.07
Engine oil	0.17	0.11	0.11	0.11	0.11
Replacement tires (calculated as a fn of VMT and wgt)	0.48	0.46	0.47	0.32	0.33
Parking, tolls, and fines (same for all vehicles)	1.06	1.06	1.06	1.06	1.06
Registration fee (calculated as a fn of vehicle wgt)	0.51	0.46	0.48	0.41	0.42
Vehicle safety and emissions inspection fee	0.62	0.62	0.62	0.62	0.62
Federal, state, and local fuel (energy) excise taxes	1.84	1.84	1.84	1.84	1.84
Accessories (assumed to be the same for all vehicles)	0.32	0.32	0.32	0.32	0.32
Dollar value of external costs (air pollution, noise, climate change, oil use)	not counted	not counted	not counted	not counted	not counted
Total lifecycle cost (cents/mile)	**38.30**	**39.97**	**42.14**	**39.29**	**40.93**
The price of gasoline, including taxes, that equates the lifecycle consumer cost of the gasoline vehicle with the lifecycle consumer cost of the electric vehicle ($/gal)	n.a.	***1.82***	***2.30***	***1.68***	***2.04***

Silverado / Large Pickup

Table A-8: Summary of Vehicle Characteristics – Silverado / Large Pickup

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate/ Mild	Moderate/ Full	Advanced/ Mild	Advanced/ Full 1
Type of traction battery	n.a.	NiMH Gen4	NiMH Gen4	NiMH Gen4	NiMH Gen4
Type of electric motor	n.a.	UQM BPM	UQM BPM	UQM BPM	UQM BPM
Type of combustion engine	4.8 L V-8	3.1 L VTEC V-8	2.3 L VTEC V-6	2.1 L GDI V-6	1.5 L GDI V-6
Total gross power of drive system (kW)	201.3	180.0	187.5	133.3	137.5
Acceleration, 0 to 60 mph, 0% grade w/payload (sec)		7.7	7.7	7.6	7.6
Gasoline engine peak power (kW)	n.a.	153.0	112.5	113.3	82.5
Electric motor peak power (kW)	n.a.	27.0	75.0	20.0	55.0
Battery module power density (W/kg)	n.a.	718	719	799	803
Battery cycle life to 80% DoD	n.a.	1,331	1,331	1,331	1,331
Battery life (years)	n.a.	7.6	7.6	7.6	7.6
Battery system specific energy (Wh/kg)	n.a.	37	37	33	33
Battery energy (kWh)	n.a.	1.80	5.10	1.16	3.10
Battery weight (kg)	n.a.	50	139	34	93
Volume of battery in HEV / fuel tank in ICEV (L)	98	10	28	7	18
Vehicle life (km)	273,530	273,530	273,530	273,530	273,530
Weight of the complete vehicle (kg)	2,159	1,793	1,933	1,460	1,517
Coefficient of drag	0.450	0.405	0.405	0.405	0.405
Fuel economy - CAFE Cycle (gasoline-equiv. mpg)	19.6	31.0	38.7	40.2	49.9
Fuel economy - EIA Cycle (gasoline-equiv. mpg)	16.1	25.4	31.7	33.0	40.9
Fuel economy - EIA Cycle (gasoline-equiv. L/100 km)	14.6	9.3	7.4	7.1	5.8

Table A-9: Summary of Vehicle Costs – Silverado / Large Pickup

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Fuel retail price, excluding taxes ($/GEG)	1.07	1.07	1.07	1.07	1.07
Full retail price of vehicle, incl. taxes and shipping ($)	**25,714**	**29,492**	**32,408**	**29,104**	**31,001**
Manufacturer's suggested retail price (MSRP) ($)	24,350	28,027	30,842	27,692	29,527
Dealer invoice price ($)	20,597	23,943	26,507	23,638	25,309
Manufacturing cost ($)	10,072	12,679	14,675	12,441	13,742
Battery contribution to retail price ($)	n.a.	2,458	6,472	1,702	4,495
Battery contribution to retail cost ($/kWh)	n.a.	1,331	1,264	1,502	1,456
ICE and engine assembly contribution to retail price ($)	4,279	4,070	3,398	3,944	3,303
Motor/controller/inverter contribution to retail price ($)	n.a.	2,133	2,794	1,980	2,561
Transmission contribution to retail price ($)	1,145	982	922	877	834
Levelized maintenance cost ($/yr)	647	739	755	711	725
Total lifecycle cost (cents/km)	48.57	51.48	55.91	49.43	52.22
Present value of lifetime cost vs. gasoline ($)*	65,797	3,943	9,944	1,163	4,945
Breakeven gasoline price ($/gal)	n.a.	1.93	2.65	1.60	2.05

*For gasoline, the present value is shown; for the HEVs, the difference in the present value vs. gasoline is shown.

Table A-10: Summary of Lifecycle Costs – Silverado / Large Pickup
(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 cents/mile)

Cost item	**ICEV**	**Moderate Mild**	**Moderate Full**	**Advanced Mild**	**Advanced Full 1**
Battery and tray and auxiliaries (NiMH Gen4)	n.a.	2.92	7.74	2.02	5.36
Vehicle, excluding battery	20.36	21.29	20.60	21.57	20.99
Motor fuel, excluding excise taxes and electricity	6.63	4.21	3.37	3.24	2.62
Fuel-storage system	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle
Insurance (calculated as a fn of VMT and vehicle cost)	9.90	10.94	11.73	10.83	11.35
Maintenance and repair, excluding oil and inspection	5.74	6.55	6.69	6.31	6.43
Engine oil	0.21	0.13	0.13	0.13	0.13
Replacement tires (calculated as a fn of VMT and wgt)	0.55	0.38	0.54	0.36	0.36
Parking, tolls, and fines (same for all vehicles)	1.06	1.06	1.06	1.06	1.06
Registration fee (calculated as a fn of vehicle wgt)	0.67	0.55	0.60	0.45	0.47
Vehicle safety and emissions inspection fee	0.67	0.67	0.67	0.67	0.67
Federal, state, and local fuel (energy) excise taxes	2.45	2.45	2.45	2.45	2.45
Accessories (assumed to be the same for all vehicles)	0.32	0.32	0.32	0.32	0.32
Dollar value of external costs (air pollution, noise, climate change, oil use)	not counted	not counted	not counted	not counted	not counted
Total lifecycle cost (cents/mile)	**48.57**	**51.48**	**55.91**	**49.43**	**52.22**
The price of gasoline, including taxes, that equates the lifecycle consumer cost of the gasoline vehicle with the lifecycle consumer cost of the electric vehicle ($/gal)	n.a.	***1.93***	***2.65***	***1.60***	***2.05***

Caravan / Minivan

Table A-11: Summary of Vehicle Characteristics – Caravan / Minivan

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	**ICEV**	**Moderate/ Mild**	**Moderate/ Full**	**Advanced/ Mild**	**Advanced/ Full 1**
Type of traction battery	n.a.	NiMH Gen4	NiMH Gen4	NiMH Gen4	NiMH Gen4
Type of electric motor	n.a.	UQM BPM	UQM BPM	UQM BPM	UQM BPM
Type of combustion engine	3.8 L V-6	2.2L VTEC V-6	1.5 L VTEC Inline-4	1.4 L GDI Inline-4	1.1 L GDI Inline-3
Total gross power of drive system (kW)	134.2	126.6	125.0	93.3	97.5
Acceleration, 0 to 60 mph, 0% grade w/payload (sec)		9.1	9.1	8.9	9.0
Gasoline engine peak power (kW)	134.2	107.7	75.0	79.3	58.5
Electric motor peak power (kW)	n.a.	19.0	50.0	14.0	39.0
Battery module power density (W/kg)	n.a.	724	722	800	805
Battery cycle life to 80% DoD	n.a.	1,331	1,331	1,331	1,331
Battery life (years)	n.a.	7.6	7.6	7.6	7.6
Battery system specific energy (Wh/kg)	n.a.	37	37	33	33
Battery energy (kWh)	n.a.	1.3	3.4	0.8	2.2
Battery weight (kg)	n.a.	35	93	24	66
Volume of battery in HEV / fuel tank in ICEV (L)	86	7	18	5	13
Vehicle life (km)	273,530	273,530	273,530	273,530	273,530
Weight of the complete vehicle (kg)	2,045	1,686	1,764	1,386	1,427
Coefficient of drag	0.400	0.360	0.360	0.360	0.360
Fuel economy - CAFE Cycle (gasoline-equiv. mpg)	22.3	38.4	47.0	49.1	59.0
Fuel economy - EIA Cycle (gasoline-equiv. mpg)	18.3	31.5	38.5	40.3	48.4
Fuel economy - EIA Cycle (gasoline-equiv. L/100 km)	12.8	7.5	6.1	5.8	4.9

Table A-12: Summary of Vehicle Costs – Caravan / Minivan

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Fuel retail price, excluding taxes ($/GEG)	1.07	1.07	1.07	1.07	1.07
Full retail price of vehicle, incl. taxes and shipping ($)	**24,541**	**27,703**	**29,368**	**27,307**	**28,929**
Manufacturer's suggested retail price (MSRP) ($)	23,264	26,335	27,950	25,983	27,554
Dealer invoice price ($)	19,376	22,149	23,607	21,831	23,249
Manufacturing cost ($)	11,224	13,512	14,716	13,250	14,420
Battery contribution to retail price ($)	n.a.	1,513	3,884	1,047	2,825
Battery contribution to retail cost ($/kWh)	n.a.	1,182	1,146	1,323	1,297
ICE and engine assembly contribution to retail price ($)	3,053	3,199	2,665	2,909	2,783
Motor/controller/inverter contribution to retail price ($)	n.a.	1,713	2,196	1,594	2,044
Transmission contribution to retail price ($)	844	762	718	679	655
Levelized maintenance cost ($/yr)	647	729	737	702	714
Total lifecycle cost (cents/km)	44.14	45.87	48.27	44.18	46.33
Present value of lifetime cost vs. gasoline ($)*	59,644	2,398	5,594	208	3,122
Breakeven gasoline price ($/gal)	n.a.	1.79	2.21	1.49	1.89

*For gasoline, the present value is shown; for the HEVs, the difference in the present value vs. gasoline is shown.

Table A-13: Summary of Lifecycle Costs – Caravan / Minivan
(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 cents/mile)

Cost item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Battery and tray and auxiliaries (NiMH Gen4)	n.a.	1.79	4.62	1.24	3.36
Off board battery-charging wiring and equipment	n.a.	0.00	0.00	0.00	0.00
Vehicle, excluding battery	19.37	20.58	20.13	20.64	20.60
Motor fuel, excluding excise taxes and electricity	5.92	3.40	2.78	2.65	2.21
Fuel-storage system	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle
Insurance (calculated as fn of VMT and vehicle cost)	7.93	8.71	9.12	8.61	9.01
Maintenance and repair, excluding oil and inspection	5.74	6.47	6.54	6.23	6.34
Engine oil	0.00	0.00	0.00	0.00	0.00
Replacement tires (calculated as fn of VMT and wgt)	0.48	0.33	0.46	0.31	0.31
Parking, tolls, and fines (same for all vehicles)	1.06	1.06	1.06	1.06	1.06
Registration fee (calculated as a fn of vehicle wgt)	0.51	0.42	0.44	0.35	0.36
Vehicle safety and emissions inspection fee	0.62	0.62	0.62	0.62	0.62
Federal, state, and local fuel (energy) excise taxes	2.19	2.18	2.19	2.16	2.16
Accessories (assumed to be the same for all vehicles)	0.32	0.32	0.32	0.32	0.32
Dollar value of external costs (air pollution, noise, climate change, oil use)	not counted	not counted	not counted	not counted	not counted
Total lifecycle cost (cents/mile)	**44.14**	**45.87**	**48.27**	**44.18**	**46.33**
The price of gasoline, including taxes, that equates the lifecycle consumer cost of the gasoline vehicle with the lifecycle consumer cost of the electric vehicle ($/gal)	n.a.	***1.79***	***2.21***	***1.49***	***1.89***

Explorer / SUV

Table A-14: Summary of Vehicle Characteristics – Explorer / SUV
(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate/ Mild	Moderate/ Full	Advanced/ Mild	Advanced/ Full 1
Type of traction battery	n.a.	NiMH Gen4	NiMH Gen4	NiMH Gen4	NiMH Gen4
Type of electric motor	n.a.	UQM BPM	UQM BPM	UQM BPM	UQM BPM
Type of combustion engine	4.0 L V-6	2.5 L VTEC V-6	2.3 L VTEC V-6	1.7 L GDI Inline-4	1.3 L GDI Inline-4
Total gross power of drive system (kW)	156.6	146.7	150.0	113.3	117.5
Acceleration, 0 to 60 mph, 0% grade w/payload (sec)		8.4	8.3	8.1	8.2
Gasoline engine peak power (kW)	156.6	124.7	90.0	96.3	70.5
Electric motor peak power (kW)	n.a.	22.0	60.0	17.0	47.0
Battery module power density (W/kg)	n.a.	718	714	811	803
Battery cycle life to 80% DoD	n.a.	1,331	1,331	1,331	1,331
Battery life (years)	n.a.	7.6	7.6	7.6	7.6
Battery system specific energy (Wh/kg)	n.a.	37	37	33	33
Battery energy (kWh)	n.a.	1.5	4.1	0.9	2.6
Battery weight (kg)	n.a.	41	112	28	79
Volume of battery in HEV / fuel tank in ICEV (L)	98	8	22	6	16
Vehicle life (km)	273,530	273,530	273,530	273,530	273,530
Weight of the complete vehicle (kg)	2,045	1,689	1,795	1,395	1,444
Coefficient of drag	0.450	0.405	0.405	0.405	0.405
Fuel economy - CAFE Cycle (gasoline-equiv. mpg)	19.9	33.4	39.9	42.2	50.2
Fuel economy - EIA Cycle (gasoline-equiv. mpg)	16.3	27.4	32.7	34.6	41.2
Fuel economy - EIA Cycle (gasoline-equiv. L/100 km)	14.4	8.6	7.2	6.8	5.7

Table A-15: Summary of Vehicle Costs – Explorer / SUV

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	Moderate Mild	Moderate Full	Advanced Mild	Advanced Full 1
Fuel retail price, excluding taxes ($/GEG)	1.07	1.07	1.07	1.07	1.07
Full retail price of vehicle, incl. taxes and shipping ($)	**28,225**	**31,686**	**33,944**	**31,759**	**33,434**
Manufacturer's suggested retail price (MSRP) ($)	26,778	30,141	32,326	30,245	31,868
Dealer invoice price ($)	22,620	25,679	27,667	25,774	27,250
Manufacturing cost ($)	11,648	14,074	15,649	14,148	15,318
Battery contribution to retail price ($)	n.a.	1,937	5,106	1,373	3,715
Battery contribution to retail cost ($/kWh)	n.a.	1,288	1,233	1,312	1,409
ICE and engine assembly contribution to retail price ($)	3,885	3,901	3,395	3,725	3,308
Motor/controller/inverter contribution to retail price ($)	n.a.	1,954	2,535	1,823	2,355
Transmission contribution to retail price ($)	1,086	968	916	872	837
Levelized maintenance cost ($/yr)	647	736	748	712	725
Total lifecycle cost (cents/km)	51.33	54.33	57.77	52.97	55.48
Present value of lifetime cost vs. gasoline ($)*	69,536	3,912	8,717	2,221	5,615
Breakeven gasoline price ($/gal)	n.a.	1.94	2.52	1.73	2.14

*For gasoline, the present value is shown; for the HEVs, the difference in the present value vs. gasoline is shown.

Table A-16: Summary of Lifecycle Costs – Explorer / SUV

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 cents/mile)

Cost item	**ICEV**	**Moderate Mild**	**Moderate Full**	**Advanced Mild**	**Advanced Full 1**
Battery and tray and auxiliaries (NiMH Gen4)	n.a.	2.31	6.13	1.64	4.45
Vehicle, excluding battery	22.52	23.64	23.07	24.18	23.76
Motor fuel, excluding excise taxes and electricity	6.55	3.90	3.27	3.09	2.59
Fuel-storage system	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle
Insurance (calculated as a fn of VMT and vehicle cost)	10.62	12.30	12.94	12.32	12.80
Maintenance and repair, excluding oil and inspection	5.74	6.53	6.64	6.32	6.43
Engine oil	0.21	0.13	0.13	0.13	0.13
Replacement tires (calculated as a fn of VMT and wgt)	0.55	0.38	0.53	0.36	0.36
Parking, tolls, and fines (same for all vehicles)	1.06	1.06	1.06	1.06	1.06
Registration fee (calculated as a fn of vehicle wgt)	0.67	0.55	0.59	0.46	0.47
Vehicle safety and emissions inspection fee	0.67	0.67	0.67	0.67	0.67
Federal, state, and local fuel (energy) excise taxes	2.42	2.42	2.42	2.42	2.42
Accessories (assumed to be the same for all vehicles)	0.32	0.32	0.32	0.32	0.32
Dollar value of external costs (air pollution, noise, climate change, oil use)	not counted	not counted	not counted	not counted	not counted
Total lifecycle cost (cents/mile)	**51.33**	**54.22**	**57.77**	**52.97**	**55.48**
The price of gasoline, including taxes, that equates the lifecycle consumer cost of the gasoline vehicle with the lifecycle consumer cost of the electric vehicle ($/gal)	n.a.	***1.94***	***2.52***	***1.73***	***2.14***

Advanced Full 2 Hybrids

Table A-17: Summary of Vehicle Characteristics – Advanced Full 2 Hybrids

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	Cavalier / Compact	Taurus / Mid-Sized	Silverado / Lg. Pickup	Caravan / Minvan	Explorer / SUV
Type of traction battery	NiMH Gen4	NiMH Gen4	NiMH Gen4	NiMH Gen4	NiMH Gen4
Type of electric motor	UQM BPM	UQM BPM	UQM BPM	UQM BPM	UQM BPM
Type of combustion engine	1.0 L GDI Inline-3	1.2 LGDI Inline-4	1.9 L GDI V-6	1.3 L GDI Inline-4	1.6 L GDI Inline-4
Total gross power of drive system (kW)	76.0	88.0	136.0	96.0	116.0
Acceleration, 0 to 60 mph, 0% grade w/payload (sec)	9.3	8.8	7.6	9.0	8.1
Gasoline engine peak power (kW)	57.0	66.0	102.0	72.0	87.0
Electric motor peak power (kW)	19.0	22.0	34.0	24.0	29.0
Battery module power density (W/kg)	800	801	802	799	802
Battery cycle life to 80% DoD	1,331	1,331	1,331	1,331	1,331
Battery life (years)	7.6	7.6	7.6	7.6	7.6
Battery system specific energy (Wh/kg)	33	33	33	33	33
Battery energy (kWh)	1.1	1.2	1.9	1.4	1.6
Battery weight (kg)	32	37	58	41	49
Volume of battery in HEV / fuel tank in ICEV (L)	6	7	11	8	10
Vehicle life (km)	273,530	273,530	273,530	273,530	273,530
Weight of the complete vehicle (kg)	1,278	1,325	1,480	1,400	1,412
Coefficient of drag	0.324	0.288	0.405	0.360	0.405
Fuel economy - CAFE Cycle (gasoline-equiv. mpg)	67.3	66.3	48.8	57.6	49.3
Fuel economy - EIA Cycle (gasoline-equiv. mpg)	55.2	54.4	40.0	47.2	40.4
Fuel economy - EIA Cycle (gasoline-equiv. L/100 km)	4.3	4.3	5.9	5.0	5.8

Table A-18: Summary of Vehicle Costs – Advanced Full 2 Hybrids

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	Cavalier/ Compact	Taurus/ Mid-Sized	Silverado/ Lg. Pickup	Caravan/ Minvan	Explorer/ SUV
Fuel retail price, excluding taxes ($/GEG)	1.07	1.07	1.07	1.07	1.07
Full retail price of vehicle, incl. taxes and shipping ($)	**18,485**	**24,256**	**30,537**	**28,471**	**32,951**
Manufacturer's suggested retail price (MSRP) ($)	17,577	23,049	29,079	27,110	31,400
Dealer invoice price ($)	15,275	19,512	24,902	22,848	26,824
Manufacturing cost ($)	8,065	11,271	13,425	14,090	14,981
Battery contribution to retail price ($)	1,583	1,718	2,806	1,760	2,312
Battery contribution to retail cost ($/kWh)	1,473	1,385	1,466	1,296	1,417
IC engine and engine assembly contribution to retail price ($)	1,756	3,116	3,790	2,900	3,522
Motor/controller/inverter contribution to retail price ($)	1,915	1,868	2,226	1,795	2,057
Transmission contribution to retail price ($)	435	725	851	667	853
Levelized maintenance cost ($/yr)	679	679	721	711	722
Total lifecycle cost (cents/km)	33.44	40.00	51.02	45.44	54.38
Present value of lifetime cost vs. gasoline ($)*	3,083	2,336	3,318	1,913	4,125
Breakeven gasoline price ($/gal)	2.04	1.84	1.86	1.72	1.96

*For gasoline, the present value is shown; for the HEVs, the difference in the present value vs. gasoline is shown.

Table A-19: Summary of Lifecycle Costs – Advanced Full 2 Hybrids

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 cents/mile)

Cost item	Cavalier/ Compact	Taurus/ Mid-Sized	Silverado/ Lg. Pickup	Caravan/ Minvan	Explorer/ SUV
Battery and tray and auxiliaries (NiMH Gen4)	1.85	2.02	3.34	2.09	2.77
Vehicle, excluding battery	12.90	17.48	21.93	21.06	24.47
Motor fuel, excluding excise taxes and electricity	1.94	1.97	2.67	2.27	2.65
Fuel-storage system	see "vehicle"	see "vehicle"	see "vehicle"	see "vehicle"	see "vehicle"
Insurance (calculated as a fn of VMT and vehicle cost)	6.37	7.83	11.22	8.90	12.66
Maintenance and repair, excluding oil and inspection	6.02	6.02	6.40	6.31	6.40
Engine oil	0.09	0.11	0.13	0.00	0.13
Replacement tires (calculated as a fn of VMT and wgt)	0.39	0.33	0.36	0.31	0.36
Parking, tolls, and fines (same for all vehicles)	1.06	1.06	1.06	1.06	1.06
Registration fee (calculated as a fn of vehicle wgt)	0.37	0.41	0.46	0.35	0.46
Vehicle safety and emissions inspection fee	0.56	0.62	0.67	0.62	0.67
Federal, state, and local fuel (energy) excise taxes	1.56	1.84	2.45	2.16	2.42
Accessories (assumed to be the same for all vehicles)	0.32	0.32	0.32	0.32	0.32
Dollar value of external costs (air pollution, noise, climate change, oil use)	not counted	not counted	not counted	not counted	not counted
Total lifecycle cost (cents/mile)	**33.44**	**40.00**	**51.02**	**45.44**	**54.38**
The price of gasoline, including taxes, that equates the lifecycle consumer cost of the gasoline vehicle with the lifecycle consumer cost of the electric vehicle ($/gal)	***2.04***	***1.84***	***1.86***	***1.72***	***1.96***

‘Prius’ Hybrid and ‘Civic’ Hybrid

Table A-20: Summary of Vehicle Characteristics – 'Prius' Hybrid and 'Civic' Hybrid

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	'Prius' Hybrid	'Civic' Hybrid
Type of traction battery (assumed, not actual)	n.a.	NiMH Gen4	NiMH Gen4
Type of electric motor (assumed, not actual)	n.a.	UQM BPM	UQM BPM
Type of combustion engine	2.2 L Inline-4	1.5 L Atkinson	1.5 L VVT Inline-4
Total gross power of drive system (kW)	85.8	85.0 (+~25 kW gen.)	73.4
Acceleration, 0 to 60 mph, 0% grade w/payload (sec)			
Gasoline engine peak power (kW)	85.8	52.0	63.4
Electric motor peak power (kW)	n.a.	33.0	10.0
Battery module power density (W/kg)	n.a.	827	622
Battery cycle life to 80% DoD	n.a.	1,331	1,331
Battery life (years)	n.a.	7.6	7.6
Battery system specific energy (Wh/kg)	n.a.	35	42
Battery energy (kWh)	n.a.	1.76	0.9
Battery weight (kg)	n.a.	51	21
Volume of battery in HEV / fuel tank in ICEV (L)	52	11	4
Vehicle life (km)	273,530	273,530	273,530
Weight of the complete vehicle (kg)	1,420	1,255	1,012
Coefficient of drag	0.360	0.324	0.324
Fuel economy - CAFE Cycle (gasoline-equiv. mpg)	30.8	58.0	56.0
Fuel economy - EIA Cycle (gasoline-equiv. mpg)	25.3	47.6	45.9
Fuel economy - EIA Cycle (gasoline-equiv. L/100 km)	9.3	4.9	5.1

Table A-21: Summary of Vehicle Costs – 'Prius' Hybrid and 'Civic' Hybrid

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 $s)

Item	ICEV	'Prius' Hybrid	'Civic' Hybrid
Fuel retail price, excluding taxes ($/GEG)	1.07	1.07	1.07
Full retail price of vehicle, incl. taxes and shipping ($)	**15,100**	**19,746**	**17,460**
Manufacturer's suggested retail price (MSRP) ($)	14,295	18,796	16,585
Dealer invoice price ($)	12,265	16,394	14,365
Manufacturing cost ($)	5,741	8,928	7,362
Battery contribution to retail price ($)	n.a.	2,538	1,017
Battery contribution to retail cost ($/kWh)	n.a.	1,443	1,157
IC engine and engine assembly contribution to retail price ($)	1,362	1,304	1,519
Motor/controller/inverter contribution to retail price ($) (incl. additional 25-kW motor/generator for Prius)	n.a.	3,558	1,687
Transmission contribution to retail price ($)	539	433	450
Levelized maintenance cost ($/yr)	605	690	668
Total lifecycle cost (cents/km)	31.43	35.54	32.25
Present value of lifetime cost vs. gasoline ($)*	42,217	5,921	1,473
Breakeven gasoline price ($/gal)	n.a.	2.57	1.74

*For gasoline, the present value is shown; for the HEVs, the difference in the present value vs. gasoline is shown.

Table A-22: Summary of Lifecycle Costs – 'Prius' Hybrid and 'Civic' Hybrid

(High-Volume Production, NiMH Gen4, 'EIA' Driving Cycle, Year 2000 cents/mile)

Cost item	**ICEV**	**'Prius' Hybrid**	**'Civic' Hybrid**
Battery and tray and auxiliaries (NiMH Gen4)	n.a.	2.97	1.18
Vehicle, excluding battery	11.58	13.17	12.53
Motor fuel, excluding excise taxes and electricity	4.43	2.25	2.33
Fuel-storage system	incl. w/ vehicle	incl. w/ vehicle	incl. w/ vehicle
Insurance (calculated as a fn of VMT and vehicle cost)	5.52	6.68	6.12
Maintenance and repair, excluding oil and inspection	5.37	6.12	5.93
Engine oil	0.14	0.09	0.09
Replacement tires (calculated as a fn of VMT and wgt)	0.41	0.39	0.27
Parking, tolls, and fines (same for all vehicles)	1.06	1.06	1.06
Registration fee (calculated as a fn of vehicle wgt)	0.41	0.36	0.29
Vehicle safety and emissions inspection fee	0.56	0.56	0.56
Federal, state, and local fuel (energy) excise taxes	1.64	1.56	1.56
Accessories (assumed to be the same for all vehicles)	0.32	0.32	0.32
Dollar value of external costs (air pollution, noise, climate change, oil use)	not counted	not counted	not counted
Total lifecycle cost (cents/mile)	**31.43**	**35.54**	**32.25**
The price of gasoline, including taxes, that equates the lifecycle consumer cost of the gasoline vehicle with the lifecycle consumer cost of the electric vehicle ($/gal)	n.a.	***2.57***	***1.74***